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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum No. 33-272

Semiannual Review of

Research and Advanced Development

July 1, 1965 to December 31, 1965

Volume I. Supporting Research and Technology for the Office of Space Sciences and Applications, National Aeronautics and Space Administration

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CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

January 31, 1966

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CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

January 31, 1966

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NOTE

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PREFACE

This document has been prepared under the direction of the Office of Research and Advanced Development of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

The Semiannual Review of Research and Advanced Development is published in three volumes directed to the appropriate NASA funding offices:

Volume I	Supporting Research and Technology for the Office of Space Sciences and Applications
Volume II	Supporting Research and Technology for the Office of Advanced Research and Technology
Volume III	Supporting Research and Technology for the Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems)

This issue reports progress for the period of July 1 to December 31, Fiscal Year 1965. The preceding issue, for the period January 1, 1965 to June 30, 1965, was published as JPL Technical Memorandum No. 33-243.

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PART A. LUNAR AND PLANETARY EXPLORATION

SCIENCE (185)

Instrumentation (185-24)

Space Chemistry (185-37)

Ionospheric and Radio Physics (185-39)

PART A. (Cont'd)

PART A. (Cont'd)

PART A. (Cont'd)

Spacecraft and Capsule Equipment Development (186-68) (Cont'd)

PART A. (Cont'd)

Spacecraft and Capsule Equipment Development (186-68) (Cont'd)

PART A. (Cont'd)

PART B. PHYSICS AND ASTRONOMY

PART B. (Cont'd)

PART C. BIOSCIENCE

PART C. (Cont'd)

PART D. MANNED SPACE SCIENCES

PART D. (Cont'd)

Planetogy (190-42) (Cont'd)

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INTRODUCTION

This volume contains a review of all supporting research and technology in progress at the Jet Propulsion Laboratory during the period July 1 to December 31, 1965, under direction of the Office of Research and Advanced Development, for the Office of Space Sciences and Applications.

The work units are arranged in numerical sequence by NASA code in each subject section. To locate a desired unit, refer to the Table of Contents under the appropriate subject heading.

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Part A
Lunar and Planetary Exploration

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SCIENCE (185)

INSTRUMENTATION (185-24)

PULSE HEIGHT ANALYZER DEVELOPMENT

NASA Work Unit 185-24-05-04-55
JPL 383-32601-2-3230
L. G. Despain

OBJECTIVE

The long-range objective of the Pulse Height Analyzer Development Program is the design of a general purpose, or universal, pulse height analyzer for space applications. The proposed instrument will possess sufficient versatility to lend itself to application by any and all of the presently conceived space radiation experiments that require either pulse height analysis or multiscaler capability. A shorter range objective is to obtain a breadboard model analyzer before the end of FY 1967.

PROGRESS

To obtain an estimate of presently conceived experiments, JPL solicited functional requirements from prominent scientists who might be considered to have a potential need for such an analyzer. Fortunately, the requirements submitted from the various scientific groups were not mutually exclusive.

A composite specification was generated, by the NASA-appointed Neutron Analysis Working Group, from the requirements submitted by the contributing scientists. This composite specification subsequently became the technical portion of the Statement of Work which was initially included in the Request for Proposal, and later in the contract for the design, development, and breadboard of the analyzer.

An investigation by the Neutron Analysis Working Group resulted in the recommendation that JPL should place the contract on a sole-source basis with Fabri-Tek, Incorporated, of Minneapolis, Minnesota. This recommendation was based on a survey conducted by the group regarding the availability of those few circuit designers considered sufficiently competent for this effort. Fabri-Tek was selected by virtue of its having acquired the services of Mr. Robert Schumann, an excellent circuit designer with a great deal of experience in the field of nuclear instrument design.

The proposal received from Fabri-Tek was acceptable, and contract negotiations resulted in a contract dated December 1, 1965, amounting to the sum of $120, 056 for the breadboard analyzer.

JPL will perform contract monitoring and provide technical and contractual liaison of the contract. JPL will also provide technical support by performing in-house investigation of troublesome functional and design problems. The completion of the breadboard will mark the end of phase I, the circuit design phase, and the beginning of phase II, the packaging phase at JPL. However, phase II will not begin until after mid FY 1967.

ANALYZER SPECIFICATIONS

The general concept of this pulse height analyzer differs little from that of conventional commercial analyzers. The instrument will accept voltage pulses of amplitudes varying from 0 to +10 v, and will classify or tabulate these pulses according to their heights into a pulse height spectrum. The spectral information is accumulated and stored in a memory and can be read out on command.

The main subunits of the analyzer will consist of an analog-to-digital converter for providing the necessary pulse-height-to-time conversion, a memory for tabulating and retaining the accumulated conversions, a programmer or logic system to sequence the operations, and a power supply for providing the necessary power to the electronic subunits. It should be noted that under this concept, the linear amplifier usually considered as part of the analyzer will here be considered as part of the detector. The amplifiers will be supplied by the experimenters as a matchmate interface between detector and analyzer.

Specifically, the analyzer will feature 512 channels of memory storage. The instrument will be capable of dividing its memory into two or three subsections and perform pulse height analysis and multiscaling simultaneously. The instrument will not only tabulate pulses according to height but will also label each analysis with information regarding the direction from which the particle came or the gain of the amplifier used in supplying the pulse to the ADC for conversion.

TEST SYSTEM

The test system objective is the precise determination of the pulse height analyzer performance, conversion gain, stability, and noise. These parameters can be deduced from a knowledge of the conversion gain, and the test equipment is designed to measure it both precisely and automatically.

Implementation consists of (1) generation of pulses of known amplitude and shape and (2) determining the results of each individual pulse height analysis. The pulse generator is made up of a digitally programmed voltage calibrator, a mercury pulser, and a linear, passive pulse forming network. Readout equipment interfaces with the analyzer under test and searches its memory after each pulse to determine the results of the analysis. A controller provides sequencing signals to the pulse generator and readout equipment and in addition formats the data for the printer, plotter, and tape punch.

These techniques and equipments are being used throughout the analyzer development. They will also be used to provide surveillance of the flight equipment from manufacture through environmental tests, spacecraft systems tests, and pre-launch tests. The resulting data will provide a definitive history of the analyzer performance and serve as a basis for the interpretation of experimental data.

FUNDING

The pulse height analyzer development program is being funded in FY 1966 from two areas. $100, 000 has come from SL, and permission was granted to apply $67, 000, carried over from the FY 1965 Post Apollo Probe Study, to the pulse height analyzer program. Expenditure of the funds is proceeding on schedule; the contract for the breadboard analyzer is being incrementally funded.

SCHEDULE

The accompanying milestone chart (Fig. 1) indicates the tentative schedule as it currently exists. The long-range schedule is shown, rather than detailed milestones for FY 1966, because a finer breakdown of the circuit design phase at this point would be meaningless.

A slightly more detailed account of the overall effort can be found in SPS 37-34, Volume IV.

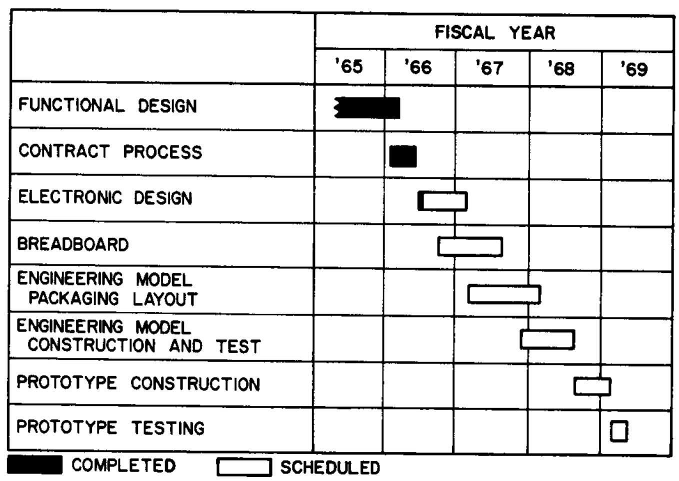

Fig. 1. Estimate of program milestones

SPACE CHEMISTRY (185-37)

X-RAY DIFFRACTION
NASA Work Unit 185-37-20-02-55
JPL 383-30201-2-3250

(This work unit is jointly funded under NASA Code 190-42-03-02-55. Refer to the Manned Space Science Section for the appropriate report.)

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FLIGHT MODEL INTERFEROMETER
NASA Work Unit 185-37-20-10-55 (818-01-06-70*)
JPL 383-32101-2-3250 (to Dec. 1965)

Reinhard Beer

OBJECTIVE

The objective of this task is to develop a flightworthy high-resolution infrared interference spectrometer for atmospheric analysis on advanced planetary missions.

PROGRESS

Despite a severe cut in manpower, development has continued steadily. An optical breadboard of the double-passed afocal retroreflecting ("cat's-eye") system has been completed and is currently under test. Focusing of the individual reflectors has proved to be rather difficult because of the method of manufacture chosen by the vendor. However, since this is a "once-for-all" adjustment, it should not create any fundamental difficulty. It has already been demonstrated that the system is indeed insensitive to minor misalignment and hence should survive a launch without difficulty.

It is still hoped that it will be possible to attach an interferometrically controlled servo drive to the system by the end of the year, but this will be entirely dependent on the availability of suitable manpower in the next half-year.

The interferometer is the subject of two publications: NASA Technical Brief 65-10295 and a JPL internal document, "An Advanced Atmospheric Temperature Sounding Experiment," by R. McClatchey, R. Beer, J. Shaw, and L. D. Kaplan. The proposed experiment would sound the Martian atmosphere at some 11 levels and would measure the abundance of such molecular species as CO_2, H_2O, O_2, N_2O, and NO_2 and any sources emitting or absorbing in the 1.2 - 5μ range.

As of December 1965, this project is transferred out of the purview of Supporting Research & Technology and into the _Voyager_ project.

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*Transferred to _Voyager_ in FY 1966.

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LUNAR AND PLANETARY GEOPHYSICAL MODELS

NASA Work Unit 185-37-20-12-55
JPL 383-32901-0-3250

R. L. Newburn

OBJECTIVE

The objective of the lunar and planetary geophysical models group is to furnish environmental models of the various bodies of the solar system in support of Surveyor, Voyager, and the advanced planning activities for future missions. Ideally these models should be available in advance of any mission requirement and updated as new information becomes available. In practice we are a new group, still catching up with immediate project requirements, and the ideal must remain an objective for future years.

LUNAR MODEL

The most important single objective of the past six months has been to satisfy the immediate requirements of the Surveyor project. A Lunar Scientific Model is being issued, section by section, as Surveyor Project Document No. 54. This document is basically a handbook of numbers, with no scientific reasons given for the stated numbers. Such reasoning will be issued independently as technical memoranda in coming months.

MARS MODEL

Two major tasks have been undertaken for Voyager. The first has resulted in an informal working arrangement with Yale Mintz of UCLA and Stanley Greenfield of RAND Corp. to expedite integration of the primitive equations of atmospheric motion for Mars. A computer program exists at UCLA and RAND for this work but has been stymied by lack of readily accessible computer time. An agreement has been reached whereby UCLA – RAND will carry out the work and publish the results using a JPL computer. Voyager project will pay for the computer time and gain immediate access to all results. The Models Group will oversee the project and interpret the results for Voyager.

A second task undertaken has been that of advising Voyager design groups on Martian atmospheric parameters. This being an area of rapid development, written material has been limited to informal notes. As the results become more settled, it is anticipated that a revised EPD on the Martian Near Surface Environment will be issued, as well as on the upper atmosphere if at all feasible.

OTHER EFFORTS

Other efforts of the Models Group have consisted of contributions to future mission planning documents about Jupiter and Venus . This work will continue in the coming six months with contributions about Mercury and comets.

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GAMMA RAY SPECTROSCOPY

NASA Work Unit 185-37-20-13-55
JPL 383-31301-2-3250

A. E. Metzger

OBJECTIVE

The gamma ray spectrometer will furnish data on the chemical composition of lunar and planetary surfaces by measuring the intensity and characteristic energy of emitted radiation. On an orbiting or roving vehicle it should detect gross differences in the composition of different portions of the lunar or Martian surface. The same instrument can be used to measure energy spectra of galactic or extragalactic sources. The objective of this program will be to show the capability of gamma/x-ray spectroscopy for the above applications, to optimize instrument design, and to develop techniques of data analysis and interpretation.

PROGRESS

A gamma ray detector configuration is being sought which possesses good efficiency and can also offer a substantial improvement in spatial resolution over a simple, single crystal. A two-crystal telescopic system has been assembled to function as shown in the schematic diagram (Fig. 1). The signals are summed when they occur in coincidence and the combined output is transmitted to a pulse height analyzer for energy discrimination and spectral display. Testing involves the measurement of pulse height resolution, spatial resolution, and count rate response as a function of gamma ray energy, crystal geometry, and orientation. In order to accelerate these tests, a hemispheric shell was constructed and coated with a suspension of uraninite ore. The preliminary arrangement for these tests is shown in Fig. 2.

Specifications for a suitable pulse height analyzer have been prepared for a long-range NASA developmental program. In addition, a 256-channel analog-to-digital converter developed for another program has been modified for use with gamma rays. The results of linearity and count rate stability tests have been entirely satisfactory.

A large, thin window proportional counter is under development, and information has been requested on commercial capabilities in this area. A developmental photomultiplier tube of novel design has been received and is about to be tested.

Joint proposals were submitted for two forthcoming NASA flight programs .

During the next six months , detector development will continue, high energy accelerator and other simulation studies will be initiated, and an analyzer developmental program will begin under contract.

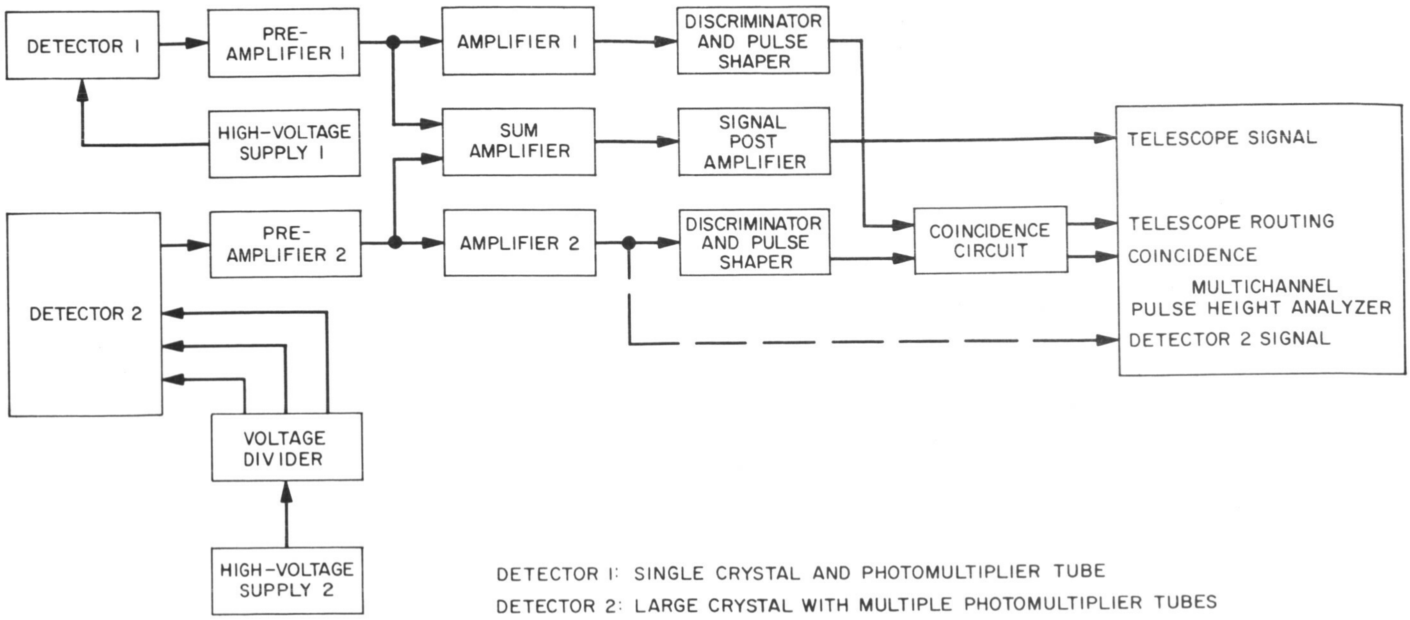

Fig. 1. Gamma ray telescope block diagram

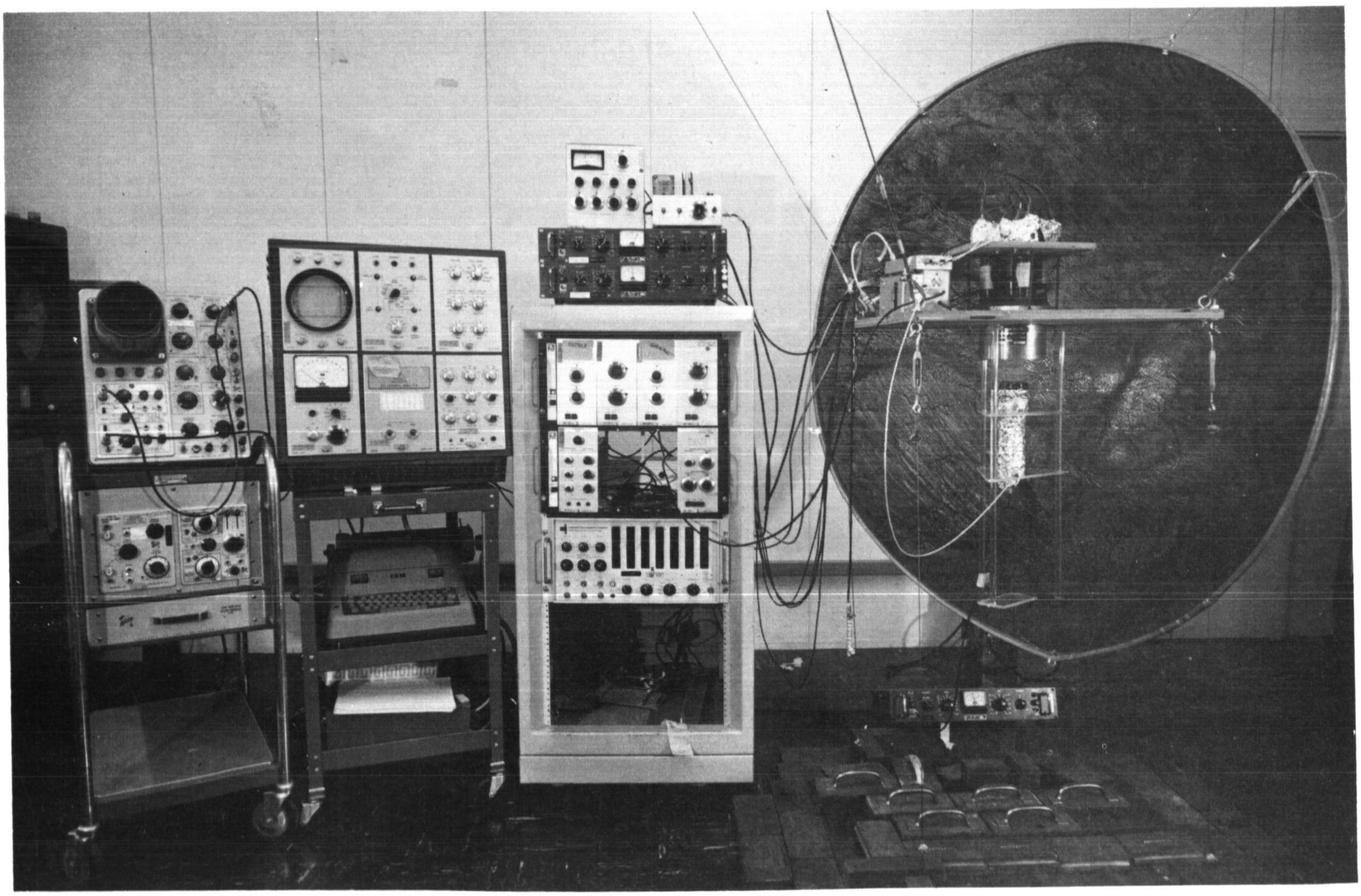

Fig. 2. Two-crystal gamma ray telescope

MICROWAVE RADIOMETER DEVELOPMENT

NASA Work Unit 185-37-25-01-55
JPL 383-30901-1-3250

F. T. Barath

OBJECTIVE

The objectives of this program are: (1) to design, develop, fabricate and test high-performance microwave radiometers in the 3-cm to 1-mm region, (2) to utilize and evaluate these radiometers in the framework of a ground-based radio astronomy observation program specifically directed at studying the Moon and the planets, and (3) to develop techniques and instrumentation for future spacecraft of the Voyager class.

PROGRESS

The work during the first half of this year was in the following areas: (1) The Table Mountain radio astronomy facility has been put into a continuous operation condition. A 10-ft parabolic antenna has been installed on the pedestal available there, and the system has been completely aligned and checked out. The variable-frequency 20- to 26-Gc radiometer has been installed on the antenna and checked out. The system was utilized for solar extinction measurements and for other observations. Reports describing these measurements are presently in preparation. (2) Bids for a precision 22-ft antenna to replace the 10-ft antenna were requested and received. Upon evaluation, it was found that the proposed 22-ft antennas would render the operation of the pedestal marginal in windy conditions, and new bids were requested for an 18-ft antenna. These bids have been received and a contract is expected to be placed by January 15, 1966. Delivery will be about May 15, 1966. (3) Bids for a low-noise, broad-band, 8-mm receiver front-end have been requested and received. A contractor has been selected and the contract negotiated; the formalities are expected to be completed and a contract in effect by January 15, 1966. (4) In-house construction of a high-performance 8-mm receiver and tail-end compatible with the low-noise receiver front-end has been started. The system will be used on the new 18-ft antenna and will be ready approximately in March 1966. (5) Some effort was spent on obtaining 8-mm phase coherent local oscillators at remote locations for eventual use in an interferometer. Preliminary results indicate that the phase synchronization can be achieved, but sources of adequate power and stability are not readily available.

Future work will include: (1) continuous operation at Table Mountain with a 2-mo interruption for operation at Goldstone, with the 20- to 26-Gc radiometer; (2) monitoring the 18-ft antenna contract, and installation at Table Mountain, followed by extensive evaluation tests; (3) monitoring and backup in-house work for the low-noise 8-mm front end; (4) completion, calibration, installation at Table Mountain, and evaluation of the new high-performance 8-mm radiometer; (5) construction of a complete phase-coherent remote local oscillator system in breadboard form for evaluation. If the evaluation proves that the system is usable, it will be tried on Table Mountain with the 18-ft and the old 10-ft antennas in a rudimentary interferometer.

MASS SPECTROMETRY ADVANCED STUDIES

NASA Work Unit 185-37-26-01-55
JPL 383-31001-2-3250

C. E. Giffin

OBJECTIVE

The long range objectives of this unit are twofold. The first is the measurement of the ionic and neutral composition of the lunar atmosphere, and the second is the compositional analysis of the Martian atmosphere. The objectives of the current fiscal year will be the finalization of the design and testing phase of a random noise quadrupole mass spectrometer (Q-pole MS) prior to breadboard development. In addition, the final testing of the Martian atmosphere mass spectrometer breadboard will be completed, emphasizing the aspects of data retrieval, ion pumping, and molecular leak inlet system.

LUNAR ATMOSPHERE MASS SPECTROMETER

The quadrupole mass spectrometer under development in this phase of the task obtains its identity with a lunar atmosphere measurement since it is felt that a lunar mission will present the earliest opportunity for its usage. While strong consideration is being given to an atmospheric experiment on the Apollo mission, it is felt that even longer range objectives than those noted above will fall within the analytical capability of this sensitive mass spectrometer (e.g., the measurements of the atmosphere of Mercury, the gaseous media in comets, and the composition of the solar wind).

Extremely good results have been obtained in our cold ionizing electron source work. It is felt essential to obtain ionizing electrons from some means other than a hot filament to ensure accurate analyses of low pressure gases. Figure 1 shows secondary electron current yields from a continuous resistive strip electron multiplier (see inset) versus the voltage applied to the device. Tritiated titanium foil was used as the primary source of electrons. Figure 2 shows a family of normalized secondary electron current yields versus the energy of these electrons. From the figure one can note that the minimum spread of electron energies occurs at an interpolated value of strip voltage of ~2100 v. It is obvious from Fig. 2 that a homogeneous beam of ionizing electrons will not result from this method of production, but this is not expected to result in any severe problems.

The last semiannual report (TM 33-243, Vol. I) contains data demonstrating our success in rejecting normally stable ions from selected portions of a quadrupole mass spectrometer spectra by injecting a 1.0-v, 520-kc supplementary field onto two of the four quadrupole rods. On the basis of these results the noise signal (shown in Fig. 3) notched at 500 kc was injected in order to selectively pass narrow mass peaks producing a high-resolution high-sensitivity mass spectrometer operating under normally low resolving power conditions. The test was unsuccessful and was later found to be attributable to too narrow a frequency notch. Two supplementary signals were then injected into the quadrupole simulating a "notch" between them in order to determine the notch width required. By varying the frequency of either signal, the "notch" could be widened or narrowed. The results are shown in Fig. 4. In this experiment data was taken with a small dc voltage applied to the rods with and without the two supplementary fields. At the supplementary frequencies noted, it appears

that a notch width of ~40 kc is required to maintain full sensitivity while at the same time obtaining good mass resolution. The lower intensity mass 28 "pass" peak is due to the fact that the supplementary field must be decreased as one scans down in mass.

Figure 5 is the schematic of a "sheet-beam" balanced modulator now under test for generating the notched noise supplementary signal. This unit will allow us to produce an input noise signal of both varying notch width and position in the frequency spectrum.

Our proposed effort in the next six months will comprise, in brief, the combining of the cold electron source with the mass spectrometer, the final testing of the notched-noise quadrupole mass spectrometer, and the optimization of ion detection efficiency. An outside contract with the AVCO Corporation of Tulsa, Oklahoma is being considered for final design and construction of the electronics associated with this instrument.

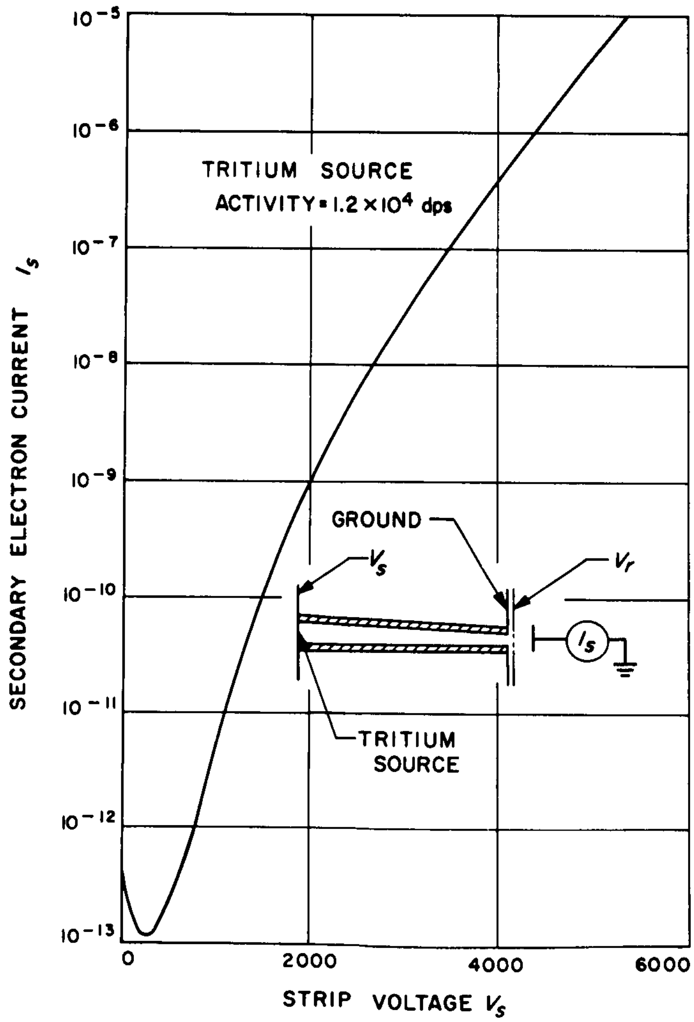

Fig. 1. Continuous strip electron multiplier output current I_S vs strip voltage V_S

PLANETARY ATMOSPHERE MASS SPECTROMETER

The efforts under this phase of the Mass Spectrometry Advanced Studies task have been to date directed towards a Voyager 71 capsule mission. An atmospheric analysis experiment had been formally proposed to NASA with Professor A. O. C. Nier (University of Minnesota) and Dr. Gerhard Schilling (RAND Corporation) as outside (external to JPL) experimenters. With the demise of Voyager 71 serious consideration is being given to upgrading the present breadboard mass spectrometer to obtain higher mass resolution and therefore improve the measurement capability of the mass spectrometer experiment for Voyager 73. This upgrading will most likely take the form of converting the present single-focusing mass spectrometer to a double-focusing instrument. While this modification would require additional weight and power, it is felt to be a worthwhile approach in view of the increased time schedule.

The present breadboard mass spectrometer has just been flown (December 21) on a high-altitude research aircraft in cooperation with the United States Air Force. Even though the data has not been fully reduced and is therefore not incorporated in this report, the flight appears to have been highly successful. A second flight is planned for the first week in January 1966. Figure 6 is a sketch of the instrumentation as it was mounted in the aircraft hatch. A new all-solid-state sterilizable electrometer designed at JPL and tested during this flight functioned perfectly. This electrometer utilizes scale switching and three feed-back resistors to attain a dynamic range of 10^5.

Our proposed efforts in data handling have been strongly curtailed by an uncommonly long procurement schedule on digitizing and printout instrumentation. However the theoretical work has continued with help from Section 324. A new digitally driven mass scanning system is being investigated at JPL which will produce a truly linear mass scale and allow for a data handling format completely controlled by the basic operation of the mass spectrometer. This system should give us the flexibility to match an optimum data output with any data limitations placed on the experiment by the spacecraft telemetry constraints. The delivery schedule on the data handling equipment is February 7, 1966, and experimentation will begin at that time.

The mass spectrometry laboratory was moved from the JPL Lake Street Annex to the main JPL facility in November. While every attempt was made to minimize lost time from this move, certain subtasks did suffer. These were:

1. Random noise testing of the lunar atmosphere mass spectrometer.

2. Ion pumping effects in the planetary atmosphere mass spectrometer.

3. Molecular leak studies for the planetary atmosphere mass spectrometer.

The laboratory is almost back into full 100% operation and no delays are anticipated.

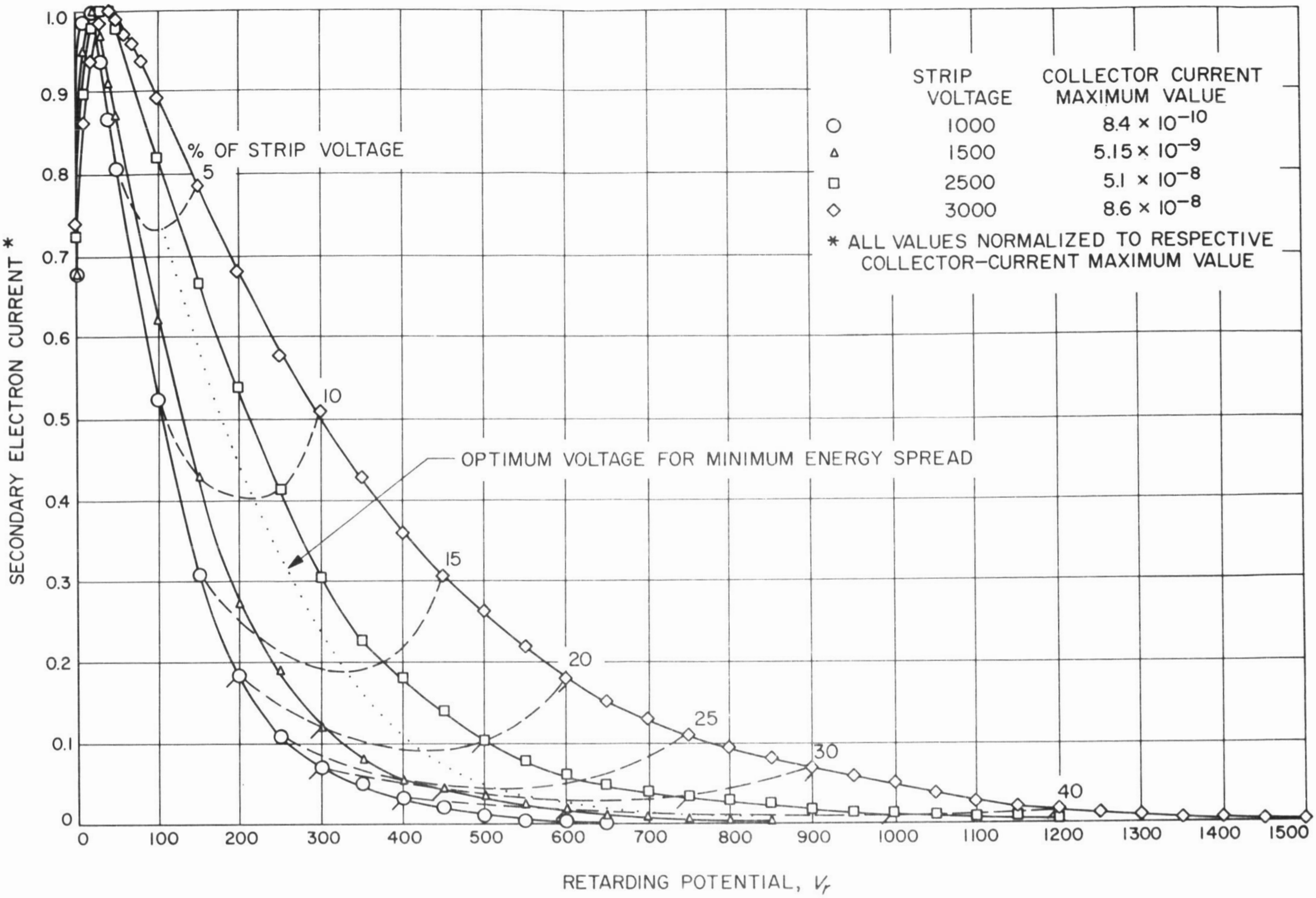

Fig. 2. Energy spectrum of continuous strip electron multiplier

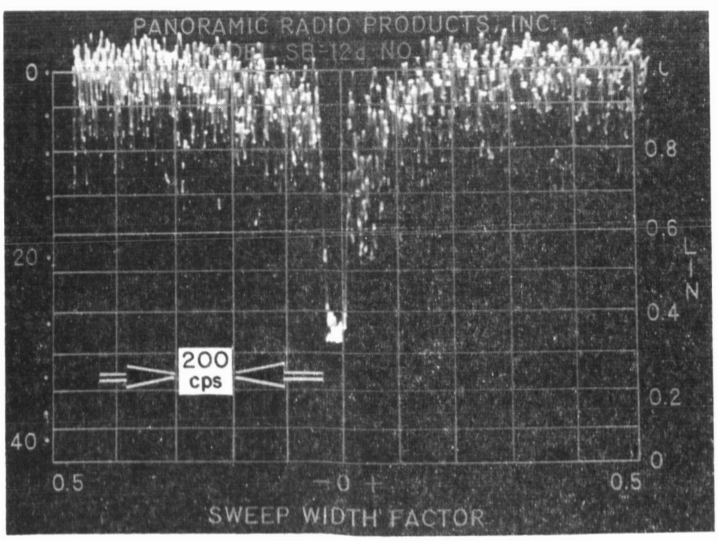

Fig. 3. Notched random noise

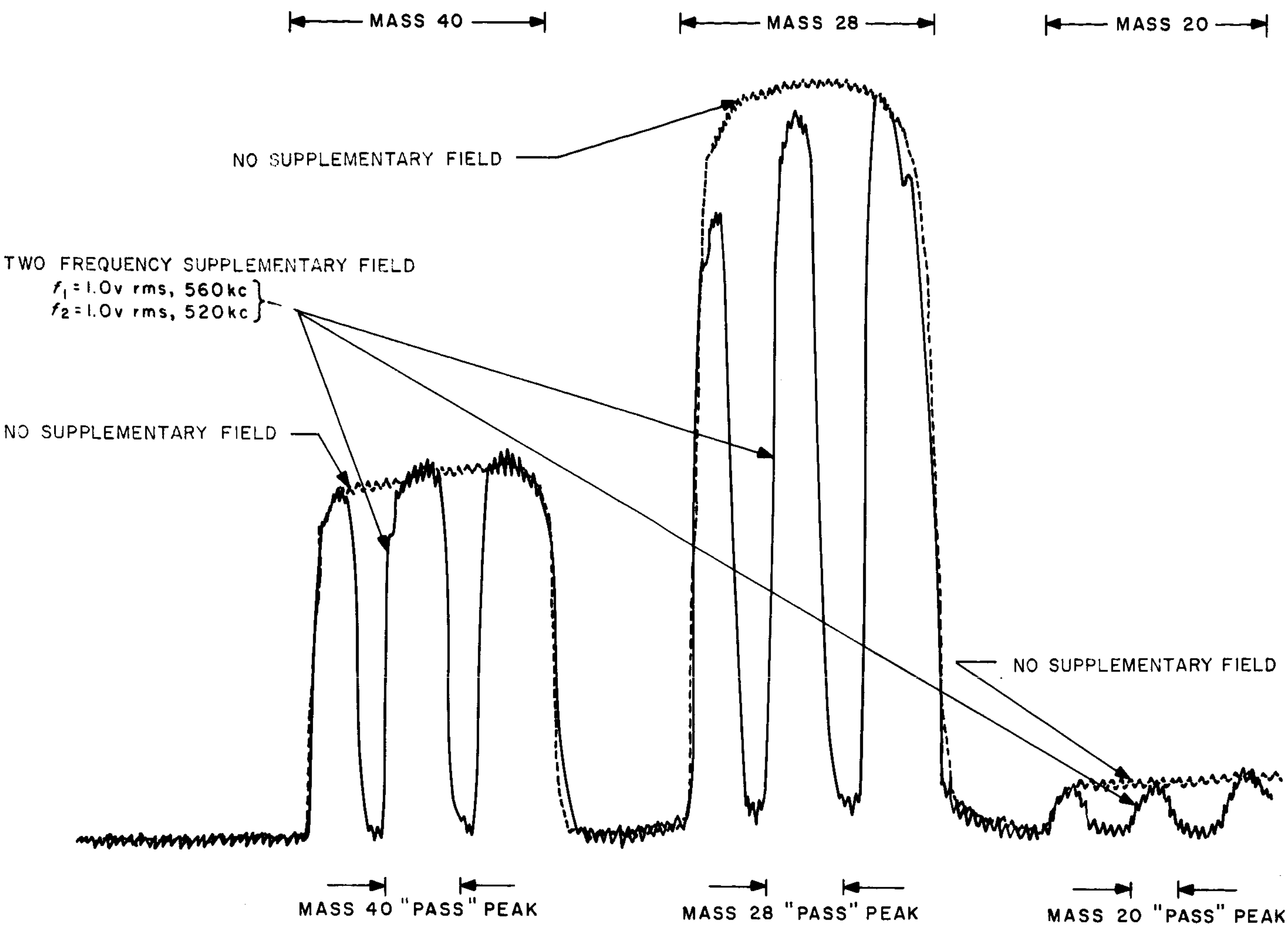

Fig. 4. Quadrupole mass spectrum — two frequency supplementary field

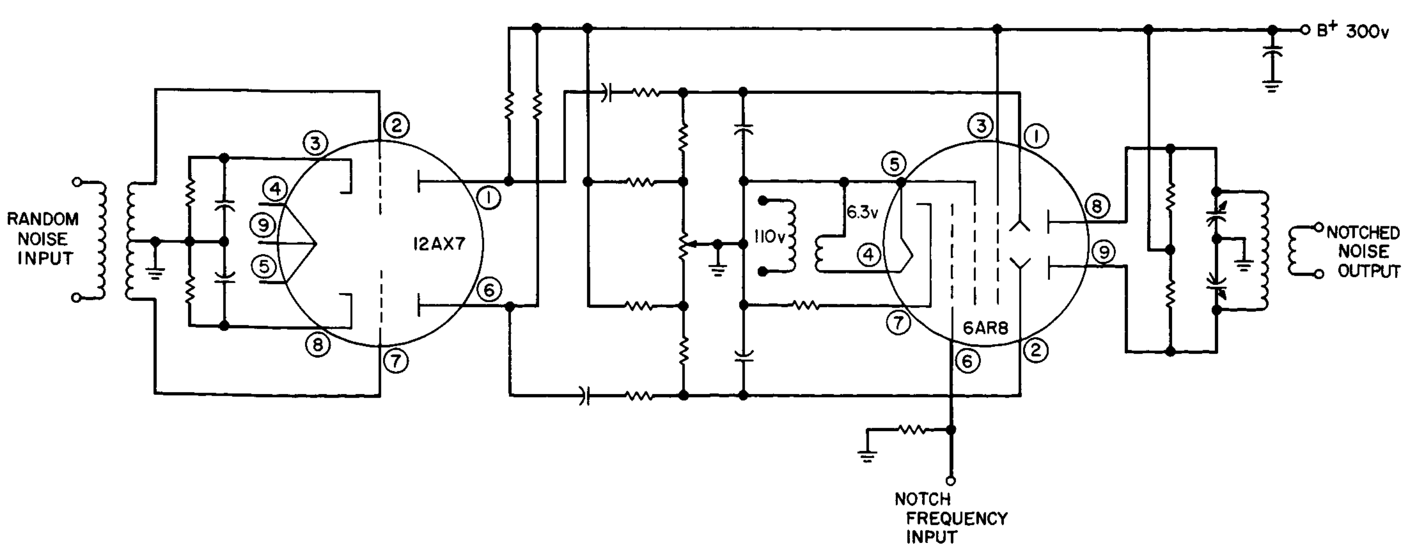

Fig. 5. Sheet beam balanced modulator

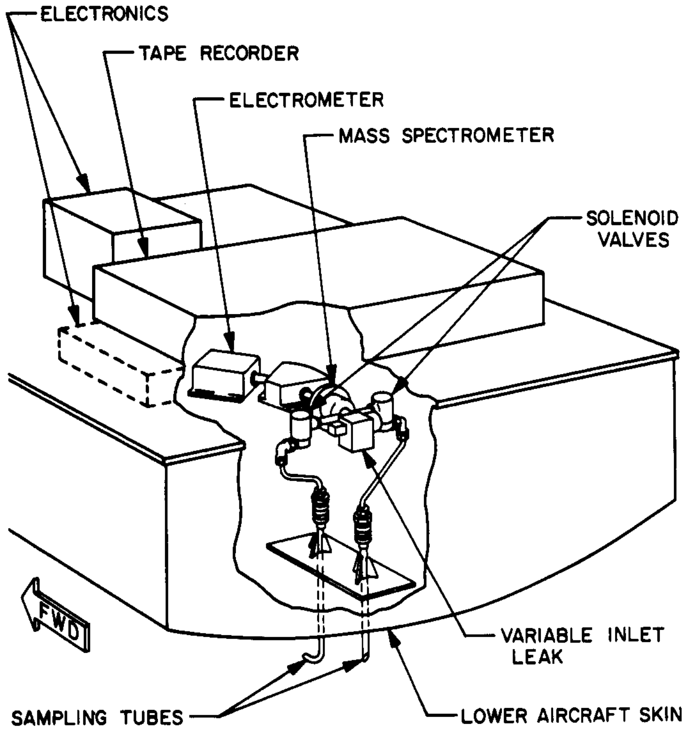

Fig. 6. Atmospheric mass spectrometer installation in research aircraft

GAS CHROMATOGRAPH COLUMN AND DETECTOR DEVELOPMENT
NASA Work Unit 185-37-26-03-55 (818-01-06-70*)
JPL 383-31201-2-3260

W. F. Wilhite

OBJECTIVE

This effort of gas chromatography atmospheric analysis has as its objective the development of column-detector systems to analyze the Mars atmosphere while on the surface of that planet.

ACTIVITIES DURING REPORT PERIOD

Performance tests were run on the micro packed column. The results of the tests showed that the micro packed column was superior in efficiency by a factor of two over any other packed column reported in the literature.

Performance tests were run on the micro thermal conductivity detector. The results of the rather rough tests showed that the micro thermal conductivity detector has a usable detection range from 100% down to a minimum of 5 ppm concentration, Other performance tests indicated that the micro thermal conductivity detector is insensitive to changes in flow of at least one order of magnitude.

A contract has been initiated with Dow Chemical to obtain material and knowledge pertaining to the revolutionary copolymer column packing material developed by Dow. All indications are this material will solve many problems in the general field of gas chromatography and especially be useful in those particular problems involving space applications of gas chromatographs.

An article was published in SPS 37-35, Vol. IV, entitled "A Micro Gas Chromatograph For Descent Analysis of the Martian Atmosphere."

A paper entitled, "Developments in Micro Gas Chromatography" was presented at the Third International Symposium on Advances in Gas Chromatography, Houston, Texas, October 21, 1965.

FUTURE ACTIVITIES PLANNED

Development of columns required to separate the constituents of the Martian atmosphere will be continued with future emphasis on all constituents including trace components of interest to biologists. First task order in the Dow Chemical contract involved the separation of all components of interest in the Martian atmosphere. The results of this task order will be received in the third quarter of FY 1966.

The test equipment for performance tests of the micro thermal conductivity detector has been brought up to date, and thorough performance tests will be run on the detector to determine the limit of sensitivity, stability, and other important parameters. This detector is low-powered, lightweight, and requires much simpler signal processing electronics than other sensitive detectors. If the performance of

*Transferred to Voyager Project in FY 1966.

this detector is suitable for spaceborne gas chromatographs, definite advantages would be attained.

Development will be started, primarily through the Dow Chemical contract, on columns to separate the life-related organic compounds of interest to the gas chromatograph/mass spectrometer experiment.

INTERFEROMETRIC INVESTIGATIONS

NASA Work Unit 185-37-26-06-55
JPL 383-30601-2-3250
Reinhard Beer

OBJECTIVE

The objective of this task is the continued investigation, development, and use of infrared interference spectrometers as high-resolution, high-luminosity devices in the laboratory and field.

PLANETARY INTERFEROMETER

The Mark II interferometer is continuing its useful work and will be used in January 1966 by the 78 in. telescope at Haute Provence, France during the current apparition of Venus. The primary objective is the total resolution of the near-infrared CO_2 bands in order to elucidate certain features observed with the Mark I instrument during the summer of 1964 by the 36 in. telescope at Kitt Peak. Dr. P. Connes of C. N. R. S., Bellevue, and his staff are again performing this work on our behalf.

The Martian spectra taken by Dr. Connes and Dr. Beer during the Spring of 1965 at Haute Provence with the Mark II instrument are currently under analysis by Dr. L. D. Kaplan. The spectra have 1 cm^{-1} resolution and a peak signal/noise of about 400, but the reduction has been complicated by the unexpectedly complex nature of the Martian near-infrared spectrum at high resolution and the rather low quality of the solar comparison spectra. To this is added the bizarre fact that the Martian spectra are at higher resolution than most available laboratory comparison spectra, making identifications difficult.

Some construction of the Mark III system has commenced at JPL, but complete plans require a knowledge of the effectiveness of some recent modifications made to the Mark II system and a decision as to the availability of a large telescope for the 1967 Mars opposition. Functional tests and, hopefully, some useful work on Venus will be done at the Coudé focus of our own 24 in. telescope during the Summer of 1966.

FAR-INFRARED INTERFEROMETER

On August 10, 1965 the far-infrared interferometer was flown on a 2-million-cubic-foot balloon from Holloman Air Force Base, New Mexico, in collaboration with the University of Denver. The system was launched, tracked and recovered after a 4-1/2-hr flight to 102,000 ft by the U. S. Air Force. All phases of the flight were technically perfect, and the instrument was recovered, almost undamaged, near Hurley, New Mexico.

The objective of the flight was to observe the far-infrared solar spectrum through the stratosphere, the region aimed at (10-100μ) having never been observed in its entirety. Unfortunately, due apparently to an offset in the University of Denver biaxial pointing control, violent signal fluctuations destroyed most of the data. However, a small portion has been retrieved and a low resolution (10 cm^{-1}) spectrum

covering the range of 10 - 70μ has been obtained. The signal/noise is low — about 20 at the peak — but sufficient to allow some analysis. This is currently in hand.

The data has demonstrated that the interferometer itself functioned perfectly, so that after some necessary modifications to the foreoptics and certain auxiliary equipment, the system will be flown again, this time hopefully to obtain several spectra at 10 times higher resolution and signal/noise.

A successful completion to this experiment would not only give us valuable engineering data on this type of interferometer, but also could make a significant contribution to the physics of the atmosphere and to solar physics, as well as allowing us to determine whether useful planetary information at longer wavelengths could be obtained from balloons.

GENERAL

Mr. D. Marjaniemi has employed the IBM 1620 computer to perform extensive ray-tracing of the type of afocal retroreflector (the so-called "cat's-eye" reflector) employed in some of our interferometers, enabling us to deduce precise manufacturing tolerances. This work will be published by R. Beer and D. Marjaniemi in the near future.

A problem in the convergence rate of the Fourier series as applied to interferometers has been investigated, and the results will be published by R. Beer and A. H. Cayford.

The entire operation will be disrupted for a time in the spring as a result of the impending move from the Lake Avenue Annex into the new building at the main site.

GEOSAMPLING (GEOLOGICAL SAMPLING)

NASA Work Unit 185-37-26-08 (818-01-06-70-55*)
JPL 544-67070-1-3220

G. M. Hotz
E. A. Howard

OBJECTIVE

The objective of the geosampling effort is to develop devices which will deliver to analytical instruments suitable samples of geological material representative of the location from which the sample was obtained.

INTRODUCTION

Past efforts in geosampling have been concentrated on drills, upon means of controlling size of cuttings produced by them, means of penetrating shallow overburdens to reach rock below, and means of efficiently acquiring particulate in the event no rock is within reach. Such devices have proved complex, and although work on them is continuing we are looking at abrading devices as a substitute for the sophisticated drill and are developing simpler devices that are essentially surface particulate samplers. This shift in emphasis has been dictated in part by a desire for simpler sampling devices and, in part, in recognition that such devices, unlike the drill, will also serve as biological samplers.

CONTRACTUAL ACTIVITIES

1. Contract No. 951178, Phase I; $18, 370; April 3, 1965 to October 1965.

   Contractor: Hughes Tool Co., Houston, Texas.

Purpose: To make a conceptual study for a lunar surface and subsurface sample acquisition and transport device, and to design a breadboard of the most promising concept.

The conceptual study yielded approximately 40 sample acquisition and transport concepts from which one was selected by JPL and Hughes for the breadboard design. The resulting design is a rather sophisticated drill type sampler with the ability to sample surface materials and rock beneath the surface without intercontamination. It employs a hollow-stemmed rotary impact drill operating in a casing. The drill tip has ports for entry of the sample that can be closed with a rotary valve. With the ports closed the sample is transported by aerosol means to a separator at some distant location. The sampling ability of the device is enhanced by the casing both in overburden and in rock under overburden. By running the casing somewhat ahead of the drill, overburden is forced into the area of the drill tip, aiding acquisition. When sampling rock under overburden the seated casing prevents overburden from entering the hole to contaminate the rock sample.

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*Transferred to Voyager Project in FY 1966

Hughes had also favored a combination milling and grinding wheel concept. However they were asked to design the drill-type sampler breadboard described above, because drilling was more in line with their experience, and negotiations were already under way with the National Research Corporation, a Division of the Norton Company, to study sampling by abrading techniques.

The final report on the contract is available as JPL reorder No. 65-757.

2. Contract No. 951178, Phase II.

Contractor: Hughes Tool Co., Houston, Texas.

Phase II of the contract called for fabrication and testing of the sampler designed in phase I. However since the concept designed in phase I was so similar to an in-house designed drill now being assembled and tested, this task is being redirected to cover the development and testing of another drill concept already existing (but not tested). This drill-sampler, shown in Fig. 1, developed by A. Dunk and U. Pineda (Section 322) is a rotary impact drill employing vibratory particle transport with the drill impactor providing the vibratory motion required for transport. Unlike the earlier version of this sampler which employed helical vibratory (spiral) conveying, this one transports axially whether positioned vertically or at any angle and will operate in a gravity field or in the absence of one.

3. Contract No. 951398; $24,856; December 3, 1965 to (330 days).

Contractor: Hughes Tool Co., Houston, Texas.

Purpose: To conduct a parametric study and experimental program applicable to a small-scale rotary impact (rotary percussive) drill which is to be employed as a combined rock-fragmenting and particle-sizing device to produce samples for geophysical and/or biological analytical instruments for lunar and planetary flights. The desired end result of this study is information which will lead to the design of a drill which will be operable with one bit of a particular design and fixed operating parameters and yet will produce a particular predetermined particle-size distribution regardless of the type of rock encountered.

If the foregoing is not feasible, be operable with one bit of a particular design and variable operating parameters which can be remotely set, on the basis of fedback information relative to the drillability of the rock encountered, to produce specified particle-size distributions.

The above is desirable because some analytical instruments require particular particle sizes and because drill cuttings tend to be finer with harder rock. In-house work has indicated that it is possible to operate a drill type sampler in such manner as to produce rock fragments of sizes usable as samples with no further processing. Hence the initiation of this contract, to develop the drill bit and the desired operating parameters. JPL is furnishing the drill testing rig to the contractor as Government Furnished Equipment for the execution of the contract.

4. Contract No. 951422; $24,813; November 30, 1965 to (180 days).

Contractor: National Research Corp., Cambridge, Massachusetts.

The contractor is to determine the feasibility of using abrasive techniques for lunar and planetary geological and biological surface and subsurface sampling. He will investigate means of particle size control when fragmenting rock, means of collecting and transporting loose overburden or fragmented surface rock to a point above the surface, and means of obtaining a sample from a submerged rock without contamination from the overburden material.

This contract was initiated after a series of in-house tests indicated that rock fragmented with some types of grinding wheels yielded x-ray diffractograms of acceptable quality; and that some degree of particle-size control could be achieved by variations in the cutting speed, pressure, grit size, and bonding material of the abrader (grinding wheels, belt, disc, etc.). The last Semiannual Progress Report discussed these tests in more detail.

IN-HOUSE ACTIVITY

In addition to the in-house activities briefly mentioned above, our efforts have been directed toward development of small, simple sampling devices which can be randomly deployed, are capable of sampling over some area to provide reasonable assurance of acquiring a sample. These samplers are intended to acquire samples from the first few millimeters or centimeters of the surface provided it is not hard rock.

1. Abrading Drum Sampler

Figure 2 shows a tethered abrading sieve drum sampler which is being developed. The outside of the hollow drum is surfaced with tungsten carbide grit and is liberally perforated with 500-μ size holes through which the sample may enter. The drum is powered by an internal reversable gas or electric motor. Rotated in one direction it travels on the planetary surface within the limits of its tether. Rotated in the other direction the reaction arm digs in or catches on some rough spot while the drum continues to rotate and collect a sample. Because of the abrading surface it will even gather samples from pumice or soft rock such as serpentine. For transporting the sample from the drum to a remote location an aerosol transport through the tether may be effective since the flow aids the entry of the sample into the drum.

2. Aerosol Transport

Litton Systems study (Contract 950771) indicated that aerosol transport through the use of an ejector pump is feasible at Martian atmospheric pressures. Accordingly such a pump was used at the inlet end of the drum sampler, described above, to transport the particulate material through a 6-ft-long 3/8 in. hose to a cyclone separator. This device will later be tested in our Martian test tank at 5-10 mb pressure.

3. Helical or Screw Sampler and Transport Device

This device, previously reported, consists of a helix (screw) rotating in a casing. The intake end can acquire directly from a planetary surface or from a more sophisticated sampler which has already gathered the sample. During this period we have worked on the problem of materials and fabrication techniques: to reduce comminution of the sample during transport, to reduce friction between screw and casing, and to produce long flexible helices and casings. Preliminary tests indicate

that comminution of the sample and wear on a metal helix are virtually eliminated by using a casing lined with silicone rubber, a material which remains flexible throughout the required temperature range. We are setting up a test stand to make friction, torque, and wear measurements of such screw and casing materials.

4. Miscellaneous Efforts

The parts for a JPL-designed lunar drill breadboard, developed on the Surveyor II X-ray diffractometer program, came in and the unit was assembled, wired, and is being functionally tested.

An idea for a "slotted rubber tube sampler" was tried with some success with a crude handmade model. While the tube lies on the planetary surface, application of internal pressure opens the slots. Upon release of pressure the slots close. Loose surface material clamped therein is then reeled in to the spacecraft with the tube.

ACTIVITIES DURING NEXT PERIOD

1. Monitor the outside contracts previously mentioned.

2. Continue in-house development of small, simple, lightweight, sampling devices more efficient than the drill in acquiring particulate samples, where bed-rock is not reached. Such devices are the abrading sieve cone, and drum, the flexible and rigid helical conveyors, the slotted tube, abrasive wheels and brushes, and aerosol methods. In general these devices will have direct application to biological, as well as geological, sampling.

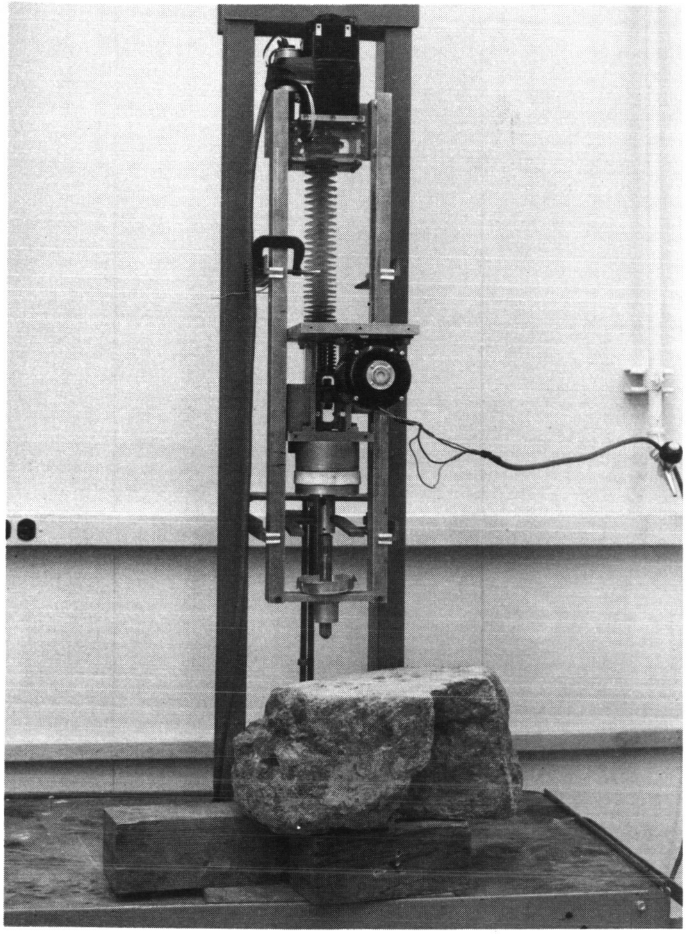

Fig. 1. Rotary impact drill — vibratory transport soil and rock sampler

Fig 2. Tethered abrading sieve drum soil and rock sampler

DETECTION OF LIFE RELATED COMPOUNDS GAS CHROMATOGRAPHY – MASS SPECTROMETERY STUDIES

NASA Work Unit 185-37-26-09-55* (818-01-06-70**)
JPL 383-31501-2-3250

C. E. Giffin

OBJECTIVE

The long-range objective of this task is to develop a gas chromatograph-mass spectrometer (GC-MS) system capable of analyzing organic compounds found on the surface of Mars. The immediate objectives are devising means through which this instrumentation can function automatically on a planetary surface. The problems to be solved are those of:

1. Removal of GC carrier gas from the instrumentation.
2. Enriching sample components in the carrier gas stream.
3. Study of automatic operation and data handling of the combined GC-MS system.

PROGRESS

Studies on the removal of hydrogen GC carrier gas have continued utilizing the test system shown in Fig. 1. The use of vapor deposited titanium as a chemical pump has been proven to be a feasible approach (see TR 33-243, Vol. I). Figures 2 and 3 show some of the data obtained in the Laboratory. The tests were performed on the basis that the GC carrier gas flow would be ~0.1 atm CC H_2 per minute. The data in Fig. 2 indicate that if 1 mm H_g pressure could be tolerated in the system (a good assumption) then 30 min of operation could be realized from the titanium vapor deposit pump tested. Figure 3 shows the quantity of hydrogen pumped per unit time with this pump. The pumping speed curve should have fallen to zero as the titanium film became saturated. The fact that it did not appears to be a gauging problem. A new gauge has been attached to the system and the higher pressure results will be checked.

Discussions have been held with Professor Stuart Hoenig of the University of Arizona on our efforts in this task. He has come up with a unique method for depositing titanium (or barium) at low power levels using an exothermic chemical reaction. This process will be investigated during the next six months. Professor Hoenig has also submitted a proposal to JPL to investigate a field ionization ion source for the GC-MS mass spectrometer. In brief, the advantage of this type of ion source is that organic mass spectra are produced with practically no fragmentation pattern and thus reduce significantly the amount of telemetered data required by an experiment of this type. Very strong consideration is being given this proposal since manpower limitations preclude any investigation of field ionization at JPL at this time.

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*Jointly funded under NASA Work Unit 189-55-02-08-55.

**Transferred to Voyager Project in FY 1966.

The gas ion source for the JPL 12-in. mass spectrometer has finally arrived after a two-month delay by the vendor (Nuclide Corporation, State College, Pa.). The instrument is being reassembled so that sample enrichment studies can begin using the diffusive separator principle.

The Lunar and Planetary Instruments Section is assisting in this task in the design of micro-diffusive separators and the impact testing of various magnet materials for the mass spectrometer portion of the experiment.

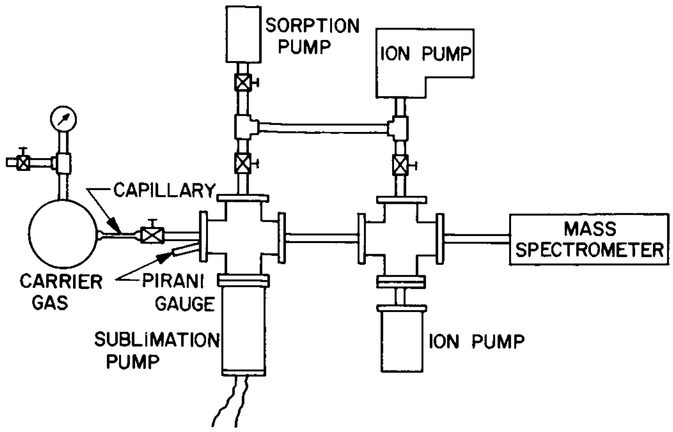

Fig. 1 Pumping system for gas chromatograph — mass spectrometer

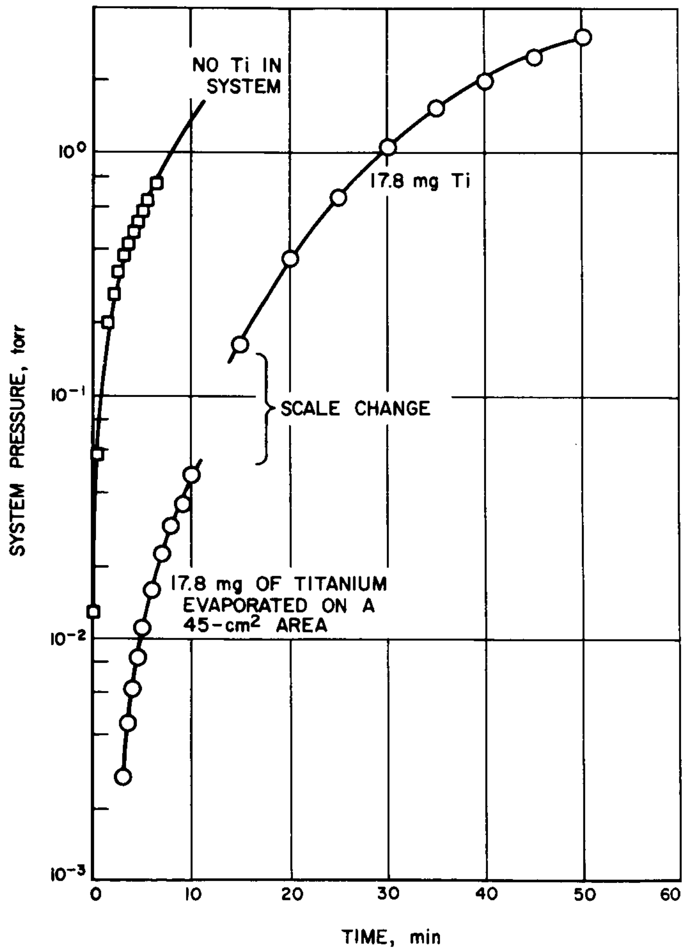

Fig 2. Pumping of hydrogen by titanium films, showing system pressure vs time

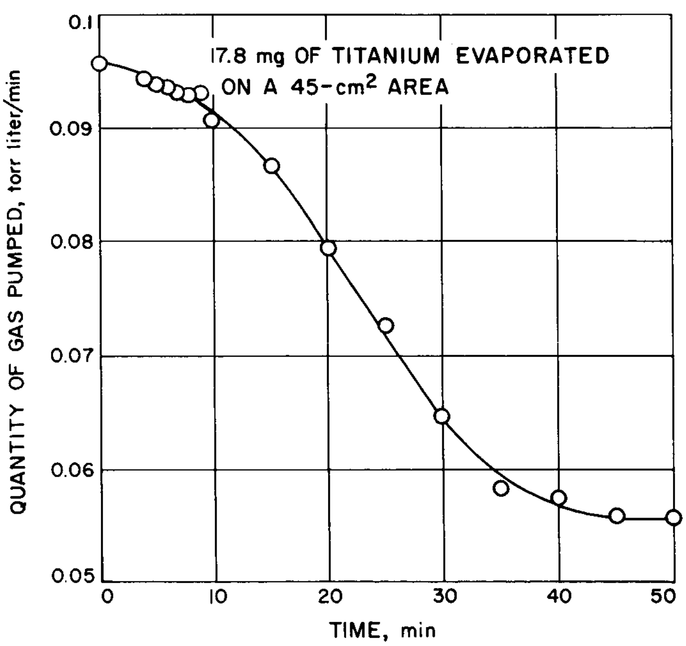

Fig. 3. Pumping of hydrogen by titanium films, showing quantity of gas pumped

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ULTRAVIOLET SPECTROMETER SCIENCE SUPPORT

NASA Work Unit 185-37-26-12-55
JPL 383-32401-2-3280
C. A. Barth

OBJECTIVE

The objective of this task is to create an ultraviolet experiment that will obtain significant scientific data from a planetary flyby spacecraft. The task includes development of the theory, the experimental physics, and the appropriate instruments and calibration techniques.

TERMINAL ACTIVITIES

A formal report, JPL TR 32-822, Ultraviolet Spectroscopy of Planets, was published on December 15, 1965.

This task was terminated at the end of September. C. A. Barth is proposing an ultraviolet spectrometer experiment for Voyager, based on the developments accomplished under this and related tasks over the past several years.

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INFRARED SPECTROSCOPY OF SYNTHETIC ATMOSPHERES
NASA Work Unit 185-37-26-16-55
JPL 383-32801-2-3250
J. M. Flournoy

OBJECTIVE

This work unit is to provide laboratory data on certain weak infrared absorption bands of CO_2, H_2O, and other gases. Such information is essential for the interpretation of astronomical spectra of planetary atmospheres and for the planning of some experiments for planetary missions. The objectives for the current fiscal year are to complete the installation and testing of the spectrographic equipment and to obtain high-resolution infrared spectra of CO_2.

STATUS OF EQUIPMENT ASSEMBLY

The 5-meter vacuum spectrograph and the 1.8-meter vacuum spectrometer (both Jarrell-Ash instruments) have been installed, aligned, tested, and are in full operating condition. The larger instrument can be used for either photographic or photometric work; the smaller spectrometer is strictly a photometric instrument. Calibration spectra of the mercury emission lines at 4358 Å have demonstrated a resolving power in excess of 1, 000, 000 for the 5-meter instrument (used photographically) and in excess of 500, 000 for the 1.8-meter scanning spectrometer. The linear dispersion of the large spectrograph is of the order of 0.3 Å per millimeter at the focal plane.

The 6-meter multiple-reflection gas cell has been installed and made leak-tight, and has achieved an optical path length of more than 500 meters while evacuated to a few microns' pressure. Provision is now being made to pressurize, heat, and cool the cell. Certain modifications in the shell design are being made in order to eliminate thermal gradients that lead to serious convection near the mirrors. This turbulence produces image movement that cannot be tolerated on the spectrographic slits.

A small, 1-meter, 40-pass gas cell was coupled to the 5-meter spectrograph, and some preliminary absorption spectra of CO_2, H_2O, and CH_3Cl were obtained in the 1.5 - 2.7μ region. A resolution of the order of 1 cm^{-1} was obtained at 1.6μ (6700 cm^{-1}) without using an exit slit, but simply allowing the emergent radiation to fall on a 3-mm wide detector mounted at the focal plane. Both tuned ac amplification and phase-sensitive detection techniques were used.

FUTURE PLANS

While the large gas cell is being completed, the small cell will be used in conjunction with the 5-meter spectrograph to prove out the detection system as well as to assist in the final design of transfer optics to go between the gas cells and the spectrometers. Efforts are under way to increase the efficiency of collecting light from the gas cells. These changes, combined with the use of cooled detectors and an increased chopping rate, are expected to produce a marked improvement in the signal-to-noise ratio, which is now of the order of 30:1 with a 2-sec time constant.

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The completed assembly will be checked out with respect to several well known bands of CO_2, after which the program will proceed to weak bands of CO_2, CH_4, and NH_3, which are of interest in the spectra of Mars, Venus, and Jupiter.

IONOSPHERIC AND RADIO PHYSICS (185-39)

HIGH ALTITUDE ROCKET-RADAR PROJECT

NASA Work Unit 185-39-05-01-55
JPL 383-90101-2-3250
Walter E. Brown, Jr.

OBJECTIVE

The purpose of this experiment is to obtain factual information about the echo behavior from a known target at altitudes in excess of 100 km. The experiment consists of looking at the Earth with radar from altitudes of between 90 and 180 km and observing the echo in both polarizations. The results of this experiment represent a key to the understanding of ground-based observations of the Moon and planets. Knowledge of the high-altitude echo behavior is a necessary and major prerequisite for the determination of surface parameters from reflection and emission characteristics obtained by remote microwave sensors.

FIELD EXPERIMENTS

The 100-kw 1000-Mc radar was flown to an altitude of 160 km on June 30, 1965 at WSMR. The altitude control system, recovery system, radar receiver, modulator, camera, and data handling systems performed normally. The magnetron failed to transmit because a loose metallic particle within the tube caused it to short out under zero-g conditions. The particle was found after a thorough post-flight analysis of the flight system and was apparently the result of a welding splash which occurred during the tube construction. Figure 1 shows a magnified view of the particle.

The preparations for the next flight include the construction of a new magnetron under special controlled conditions, the modification of the magnetron shelf structure to decrease the shelf deflection under lateral loads, and a calibration and qualification of all subsystems. The magnetron is scheduled to be delivered to JPL the first week in February 1966, and the flight is tentatively scheduled for the first week in April 1966. Figure 2 shows the flight system undergoing vibrational tests.

LABORATORY MEASUREMENTS

A total of 43 samples were taken from various locations in the radar target area in the Tularosa Basin. Preparations are nearly completed for measuring the permittivity (dielectric constant), loss tangent (conductivity), water content, mineral content, void ratio, and distribution of grain sizes. The permittivity and loss tangent measurements have been made with a newly devised technique, which is potentially suitable for a flight instrument on a soft lander. The electrical measurements will be made at both 1000 and 10,000 Mc. It is expected that the cataloging of the parameters mentioned above will be partially completed by the end of this fiscal year.

In addition to the active system measurements, passive measurements are also being prepared. A 10,000-Mc radiometer has been constructed for the measurement of the temperature phase lag and Brewster angle in sand-like samples. The purpose of these measurements is to determine the actual relationship between emissivity and reflectivity and to check the theoretical expressions for the phase lag, given the electrical and thermal properties of the material.

ASSOCIATED WORK

Reports Published

Brown, W. E., Jr., "High Altitude Rocket Radar Project," SPS 37-30, Vol. IV, December 31, 1964.

Barath, F. T., "High Altitude Rocket Radar Project Implementation," SPS 37-31, Vol. IV, February 28, 1965.

Brown, Barath, Jordan, Laderman, Martin, Friedman, Gutierrez, High Altitude Rocket Radar Project, (Progress Report) TM 33-196, January 15, 1965.

Reports in Preparation

Laderman, A., Radar Receiver Calibration.

Jordan, R., Electrostatic Forces on Metallic Particles in a Zero-G Field.

Brown, W. E., Jr., Radiowave Reflection/Emission Research and Spacecraft Sensor Applications Planning Document.

Inventions Submitted

Brown, W. E., Jr., Barath, F. T., Radiowave Emission and Reflection Sensor, Case No. 875.

Brown, W. E., Jr., Permittivity and Conductivity Sensor.

Meetings

NASA/OSSA/SM radar team executive panel meeting at Lawrence, Kansas; September 30 - October 1, 1965; discussion of P. Badgley's AES radar program.

NASA/JPL rocket-radar meeting in Washington, D. C., November 30, 1965; discussion of status and perspective of rocket-radar work; request by JPL for additional funding.

Major Procurements

Magnetron, Raytheon; $12,000.

Mechanical Structural Margin Study, Space General; $10,000.

Traveling Wave Tube for AFC Testing, Alfred Electronics; $2,150.

Record and Reproduce Heads, Ampex; $3,390.

PIN Modulators for Sample Measurements, Hewlett & Packard; $2,400.

FUTURE ACTIVITIES

It is expected that the laboratory measurements and the data analysis from an April 1966 flight will continue into the next fiscal year. Possible NASA aircraft Convair 990 flights over the same target area with the 1000-Mc radar are being investigated. Additional rocket flights, as necessary, are planned for FY 1967 as well as field measurements of the penetration of the electromagnetic wave into the surface. The system design and breadboard test of an active-passive stereo imager will be carried out as a natural extension of the instrumentation development effort in the next fiscal year.

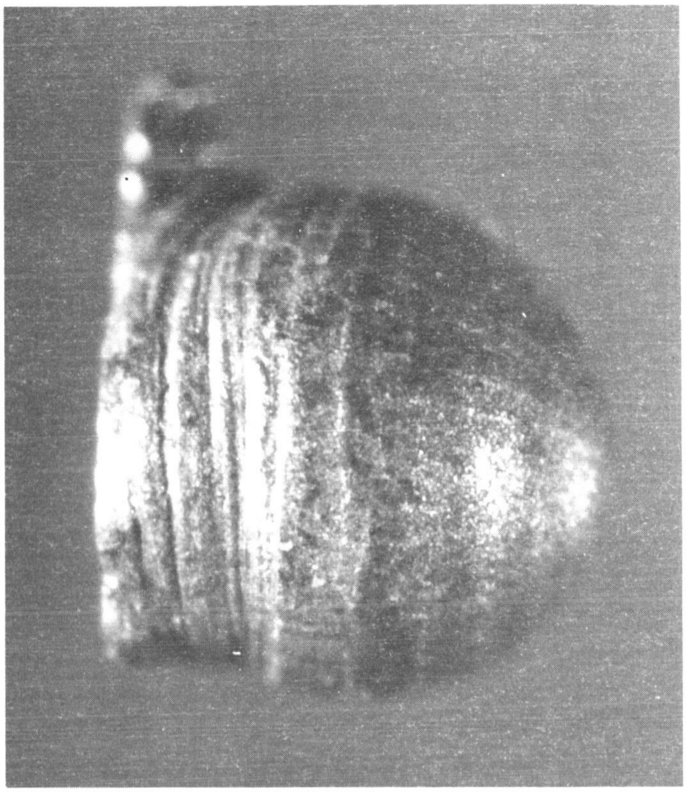

Fig. 1. Particle found in QK1264 magnetron flown in Aerobee 4.105

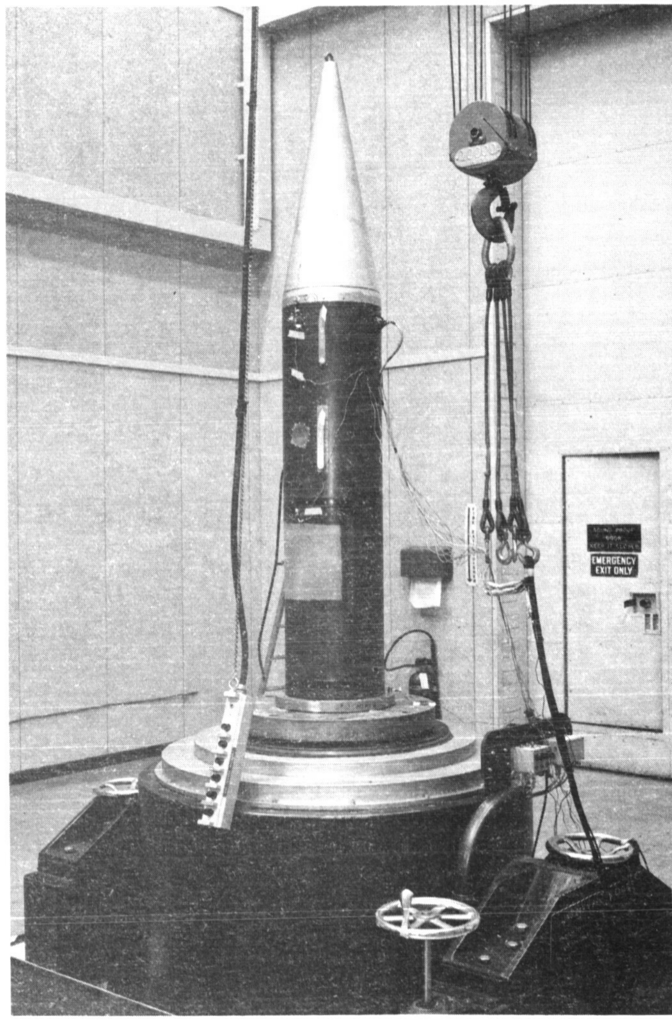

Fig. 2. Vibration test of rocket-radar payload, November 5, 1965

ASTRONOMY (185-41)

OPTICAL ASTRONOMY

NASA Work Unit 185-41-21-01-55
JPL 383-10201-2-3250
Ray Newburn

OBJECTIVE

The objective of the optical astronomy group is the application of all available techniques of ground-based optical astronomy to the study of the bodies of the solar system in order to furnish the best possible description of the surfaces and atmospheres of those bodies to engineers for spacecraft design and to engineers and scientists for experiment design. The program includes the development of our own observational facilities, the use of other existing facilities whenever feasible, and theoretical work of interpretation and in support of the observational program.

EQUIPMENT

As noted in the last semiannual report,(JPL TM 33-243, Vol. I), a contract was signed June 8 for a new 24-in. reflector. Work has proceeded normally on this instrument, and the latest progress report from the contractor states that it will be completed about January 27. It will then be shipped to Table Mountain for installation in early February. The building to house the telescope is structurally complete, including the dome, only a small amount of finish work remaining uncompleted at the time of this report. Service requests to add a rising observation floor and a Coudé observing room to the 24-in. facility have been submitted to NASA Headquarters, and are awaiting approval to proceed with final design and construction. Preliminary planning is under way on a dark room and a single-camera high dispersion spectrograph.

A new dome was installed on the 16-in. facility in August. This dome has since withstood rain driven by winds in excess of 100 mph without leaking. It has also remained leak free while undergoing a 4-1/2-in. rain in less than 4 hr. Either of these conditions would have meant a virtual flood inside the observatory with the old dome.

Equipment for a photographic lunar luminescence patrol has been completed and tested. The only problems proved to be due to poor electrical connectors supplied commercially. The equipment is now in operation on every clear night when the Moon is above the horizon.

INTERNAL OBSERVING PROGRAM

A visual patrol of the lunar crater Aristarchus was carried on for 21 mo. This has been reported in SPS 37-34, Vol. IV (Ref. 1). This search for small "red spots" has now been taken up by several other groups. The Table Mountain effort is now to be concentrated on a patrol utilizing photographs taken automatically once each minute through alternate interference filters in a search for large scale luminescence

This patrol has just begun. It will still be necessary to make guiding corrections through the 16-in. reflector, however, and a search for spots will continue at such times.

A very extensive Mars patrol was carried out by C. F. Capen, Jr. from September, 1964 through July, 1965. This was summarized very briefly in SPS 37-34, Vol. IV (Ref. 2). A major formal report is in preparation and will be submitted for publication shortly after the first of the year.

Comet Ikeya-Seki was discovered in Japan on September 18, 1965 (Fig. 1). Table Mountain Observatory obtained its first photographs of the comet on September 25, and Capen and Young continued to take photos on every clear day for the succeeding two months. These will be combined with results of the radio astronomy group in a formal report later this fiscal year.

We have continued cooperation with the International Planetary Data Centers in Meudon, France, and Flagstaff, Arizona. One hundred and ten composite photos of Mars were prepared by Young from Mars patrol data and delivered to each center this past fall, and addiditional material is in preparation for shipment.

EXTERNAL OBSERVING PROGRAM

Robert Younkin has continued reduction of spectrophotometric data taken with the Mt. Wilson 60-in. reflector. His work on the Martian surface reflectivity was reported at the Caltech Planetary Astronomy Conference in September and has been accepted for publication in the Astrophysical Journal (Ref. 3). Younkin also presented a paper with G. Munch of Caltech on "Visible and Near Infrared Spectrophotometry of Saturn's Rings" at the December meeting of the American Astronomical Society in Berkeley.

R. Schorn and H. Spinrad have completed their reduction of data on the Martian CO_2 abundance taken at the last opposition of Mars. The results have been submitted to the Astrophysical Journal. Their work on water vapor abundance will follow in a few weeks. Preliminary results of both studies were presented at the Caltech meeting in September.

The spectroscopic work on the major planets and their satellites by Spinrad, Newburn, Younkin, and Schorn, being of lesser program importance, has been treated accordingly. Reduction of existing data will be carried out this coming spring. An observing run by Newburn and Spinrad on the Kitt Peak 84-in. reflector in November was virtually unproductive of new observational results due to bad weather.

A certain amount of stellar "fill-in work" is necessary if telescope time is not to be wasted when the planets are not properly placed in the sky. Two papers based on such work have been accepted for publication (Ref. 4 and 5).

The remaining six months of this fiscal year will be devoted almost entirely to publication of results of previous observations. Besides the Mars and Comet data a large collection of Venus material must be reduced at Table Mountain. Younkin's earlier observations have supplied him with data for several additional papers. Schorn will have an observing run at the 82-in. McDonald Observatory reflector in

January. Newburn will concentrate on bringing the new 24-in. observing facility into operation and reduction of his existing major planet observations. A comprehensive new program will be presented in the spring for FY 1967.

Fig. 1. Comet Ikeya-Seki as photographed at Table Mountain Observatory, October 28, 1965, 12:54 UT, 6-min exposure on plus-X film using a Contarex 135 mm lens at f/3.5

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1. Young, J. W., "Aristarchus Observations," SPS 37-34, Vol. IV, pp. 183-184, August 31, 1965.

2. Capen, C. F., Jr., "Mars Patrol 1964-65," SPS 37-34, Vol. IV, pp. 184-187, August 31, 1965.

3. Younkin, R., "A Search for Near Infrared Features on Mars," Optical Journal, to be published in May 15, 1966 issue.

4. Spinrad, H., R. Newburn, R. Younkin, and D. Pyper, "Further Studies of the Infrared Spectra of Cool Stars – The Water Deficiency in Stars and the Variation of Water Abundance with Mira's Phase," Astrophys. Journ., to be published in February 15, 1966 issue.

5. Spinrad, H., and R. Younkin, "On the Infrared Bands of Vanadium Oxide in Three Cool Miras," Pub. of the Ast. Soc. of the Pacific, in press.

RADIO ASTRONOMY
NASA Work Unit 185-41-21-02-55
JPL 383-10301-2-3250
R. L. Carpenter

OBJECTIVE

The objective of the radio astronomy program is to increase our understanding of the Moon and nearer planets by means of (1) passive radio astronomy at centimeter and millimeter wavelengths and (2) ground based radar observations. In particular, programs have been or are underway (1) to determine accurately the transition region in Venus' microwave spectrum in the region of 13.5 mm, (2) to measure the brightness temperature of Jupiter in the region of the NH_3 band at 12.5 mm, (3) to radiometrically map the Moon at 3.3 mm, (4) to investigate the problems associated with the construction of an 8- to 13-mm interferometer, and (5) to study Venus by ground based radar (in the near future Mercury and possibly the Moon will be included).

VENUS MICROWAVE OBSERVATIONS

From July 3 through July 19, 1964, Venus was observed at eleven frequencies between 20.6 and 24 Gc. The observations were made using the 30-ft dish at Goldstone. The results were presented in the preceeding semiannual report (JPL TM 33-243, Vol. I). In summary, a broad minimum centered between 21.5 and 22.0 Gc is suggested as well as the possibility of fine structure. The water line may have been observed in emission. There was also a suggestion that the brightness temperature at 22.23 Gc varies with time. When both the 2800 Mc solar flux and the Venus data are cross-correlated versus date, a strong correlation results with a lag of between one and two days. A report on the results has been published in SPS 37-36, Vol. IV.

An observational program will be made during the 1966 Venus conjunction to obtain more data on both the solar flux relation and the variability of the 22.23-Gc temperature. Negotiations have been completed between the Space Science Division and the Telecommunications Division for use of the 30-ft dish at Goldstone for observations of Venus between February 6, 1966 and April 15, 1966. Preparations are underway to meet this schedule.

JUPITER MICROWAVE OBSERVATIONS

During December and January 1964-65, Jupiter was observed at 23.445, 23,900, and 24.005 Gc near the NH_3 band; the brightness temperatures obtained were 111, 144, and 134°K, respectively. The relative probable error between these values was about ±6°K. A very weak but positive correlation with solar activity was found for two of the three frequencies with a lag of about 12 days. The observations need repetition; however, due to manpower limitations no observations are planned during Jupiter's 1966 opposition.

TABLE MOUNTAIN RADIO OBSERVATORY

A concerted effort was made since the preceeding semiannual report (JPL TM 33-243, Vol. I) to bring the Radio Astronomy Facility at Table Mountain into operational condition. The purposes of this effort were:

1. To prepare the site as nearly as possible for the 18-ft-diameter millimeter wave dish to be installed in the early spring of next year. Extensive observations were made so that the polar axis of the antenna pedestal could be aligned accurately.

2. To check out, using celestial objects, the characteristics of the 19-25-Gc radiometer that is to be used on the 30-ft dish at Goldstone for observing Venus in 1966. Partly for the foregoing reasons and partly for its intrinsic value, comet Ikeya-Seki was observed with the 10-ft dish at Table Mountain. Some of the results will be mentioned later.

3. To optimize the operational techniques to be utilized during the 1966 Venus observing program at Goldstone.

MOON MILLIMETER OBSERVATIONS

Observations of the moon at 3.3 mm were made prior to this semiannual report in a joint effort between JPL and the Aerospace Corporation using their 15-ft dish. The antenna beam width was 2.9 ft. This allowed the construction of high angular resolution maps of the 3.3-mm thermal radiation of the Moon. The analysis showed that the maria are warmer than the mountains by $3.0 \pm 0.3^\circ K$ averaged over a lunation, which is larger than would be expected from albedo considerations. The first report of the results has been accepted for publication in the Astrophysical Journal Supplement No. 108.

Analysis of the data has continued in an attempt to learn more about the lunar surface composition. The observed microwave temperature variation during a lunation has been compared with predictions based on models ranging in complexity from one in which certain parameters of the lunar material (density, specific heat, thermal conductivity, and microwave absorption coefficient) are homogeneous with depth and across the Moon's surface, to one in which these parameters are nonhomogeneous with depth and across the surface. Values for the parameters describing these models were subjected to constraints imposed by infrared observations of the lunar nighttime surface temperature. The simple model incorporating vertical and horizontal homogeneity was incapable of accounting for the microwave and infrared observations simultaneously. Allowance for vertical nonhomogeneity (2-layered model) failed to improve the situation. The model consisting of thick dust but interspersed with areas of rock covered with a thin layer of dust was also impossible to reconcile with the observations. Exposures of bare rock afforded some improvement, but not nearly enough to be acceptable. It has been concluded that the Moon's surface is too complicated to be represented by these models. Possibly more acceptable solutions would result by allowing the thermal conductivity and specific heat to be dependent on temperature. A report on this work has been completed and should be submitted for external publication during the first quarter of 1966.

3.2-mm MERCURY AND VENUS OBSERVATIONS

In October a new program was initiated between JPL and the Aerospace Corporation using their 15-ft dish to observe Mercury and Venus at 3.2 mm. Initial observations of Mercury appear to confirm Aerospace's previous results that the planet is cold — $\sim 200^\circ K$ — and shows no phase variations. The Venus observations that have been made to date have not yet been reduced.

COMET IKEYA-SEKI OBSERVATIONS

The tail of comet Ikeya-Seki was observed at a 14.56 mm using the 10-ft dish at Table Mountain. Since the width of the tail filled the 1/3 deg beam of the antenna, the measurements are a very sensitive test for microwave emission. No radiation was detected. The brightness temperature of the tail must have been less than 0.06°K.

8- TO 13-mm INTERFEROMETER

Discussions have been underway between the Radio Astronomy group and the Radio Science group on problems associated with an 8- to 13-mm interferometer. It is hoped that within the next 6 to 9 mo an interferometer can be set up on Table Mountain using the 10- and 18-ft dishes. This will be an experimental model to be used to obtain engineering information. This will be useful for the design of a larger facility which may possibly incorporate two of the 30-ft dishes at Goldstone.

VENUS CW RADAR OBSERVATIONS

The analysis of the 1964 CW Venus radar experiment has been completed. A report on the results was submitted in November for publication in the Astronomical Journal. A paper was presented at the Gordon Research Conference on "Chemistry and Physics of Space," in July, 1965, held at Tilton, New Hampshire. Also, a review paper on radar astronomy was co-authored with members of the Telecommunications Division and published in the IEEE Spectrum, October, 1965.

The analysis of the CW radar data indicates that the polarized and depolarized reflectivities are 0.114 ±0.01 and 0.0067 ±0.005, respectively. These results lead to an average dielectric constant of the surface of 3.75 ±3. The bandwidth data, taking into account possible systematic errors, indicates a sidereal period of 250^{+4}_{-7} days retrograde. The north polar axis is pointed toward $\alpha = 255^{\circ}{}^{+10^{\circ}}_{-4^{\circ}}$, $\delta = 68^{\circ} \pm 4^{\circ}$. The obliquity of Venus' axis to its orbit pole is about 7°. Possible identification of the 1964 surface features with those observed in 1962 indicates the period may be near 244 days retrograde.

Preparations for the 1965/66 Venus CW radar program have been completed and observations began in early November, 1965. The spectral analysis computer program was completely revised in order to use special purpose equipment at Goldstone to obtain the autocorrelation coefficients of the signal. This has resulted in reducing the IBM 7094 computer time by about a factor of 10.

PLANETOLOGY (185-42)

PETROGRAPHIC STUDIES
NASA Work Unit 185-42-20-02-55
JPL 383-20201-2-3250

A. A. Loomis

OBJECTIVE

The objective of this task is to develop a remotely operated petrographic microscope for use in the investigation of planetary surfaces. The objectives of a lunar and planetary petrography experiment are to delineate as specifically as possible the nature of the processes which have operated on a given planetary body. The experiment is designed:

1. To observe rock textures.

2. To determine the gross mineralogical character of the sample and identify phases which occur in small amounts.

3. To detect the presence of glass and estimate its composition.

4. To determine the size and shape distribution of particulate surface materials.

The techniques employed in the experiment and the results of the program through FY 1965 are discussed in JPL TR 32-785.

INSTRUMENT DEVELOPMENT

JPL Contract 951273 was let to Electro-Optical Systems, Inc., Pasadena, to design a prototype model of a petrographic microscope. The contract is cost plus fixed fee and totals $63,050. Work should be completed near mid-April 1966. A conceptual drawing of the prototype is shown in Fig. 1.

The first phase of the contract is the development and construction of a demonstration model of the oscillating particle separator. This phase will be completed in early January 1966, pending successful testing of the model. This first phase was scheduled for completion in mid-December 1965. The work was delayed both by slow delivery of components and by an increased complexity in the actual design and fabrication. The increased complexity has resulted in a request by Electro-Optical Systems for $4,998.00 additional funding.

The design and fabrication of the feasibility demonstration model of the material handling mechanism of the microscope is completed. The model has been tested in atmosphere for material separation capabilities and, in a preliminary fashion, for material transfer characteristics. Both material separation and transfer appear satisfactory.

Transfer of material thus far has been to a sticky cellophane tape. Transfer to a thermoplastic will be tested January 5, 1966. Tests in the vacuum chamber will be conducted immediately thereafter.

The mechanism incorporates an oscillating shaker equipped with three bins: a hopper bin, a bin for 50- to 300-μ particles and a bin for particles less than 50 μ. The bins are separated by screens which keep out particles larger than the 50- or 300-μ sizes. Both screens are stainless steel. In its present configuration the shaker is driven through a crank-arm at 20 cps by a dc motor. Total shaker travel is ±5 deg. A gas flow is introduced into the shaker at the hopper bin. This gas flow through the three bins is intended to aid in moving particles downstream. Nodules of Zerlon plastic are placed in the hopper and in the coarse bin to aid in material transfer, to stir up the material and thus present a maximum of material to the screen, and to unblind the screens by bouncing against them and thus shaking particles loose. The nodules are 0.075 diameter x 0.175 cylindrical particles of the same Zerlon material of which the plastic sample slide is made. This introduces no new material to the system.

The model is shown in Figs. 2 and 3. The hopper is uncovered in Fig. 2 to show the bins and location of the screens. The hopper oscillates ±5 deg on a bearing at its right-hand end, throwing the particles against the screens. The tube from the left-hand end is an exhaust pump which tends to draw particles through the screens. Particles smaller than 8 μ are exhausted with the air through a filter.

Figure 3 shows the hopper with the ports in the cover from which the material will be thrown against a hot thermoplastic sheet immediately above.

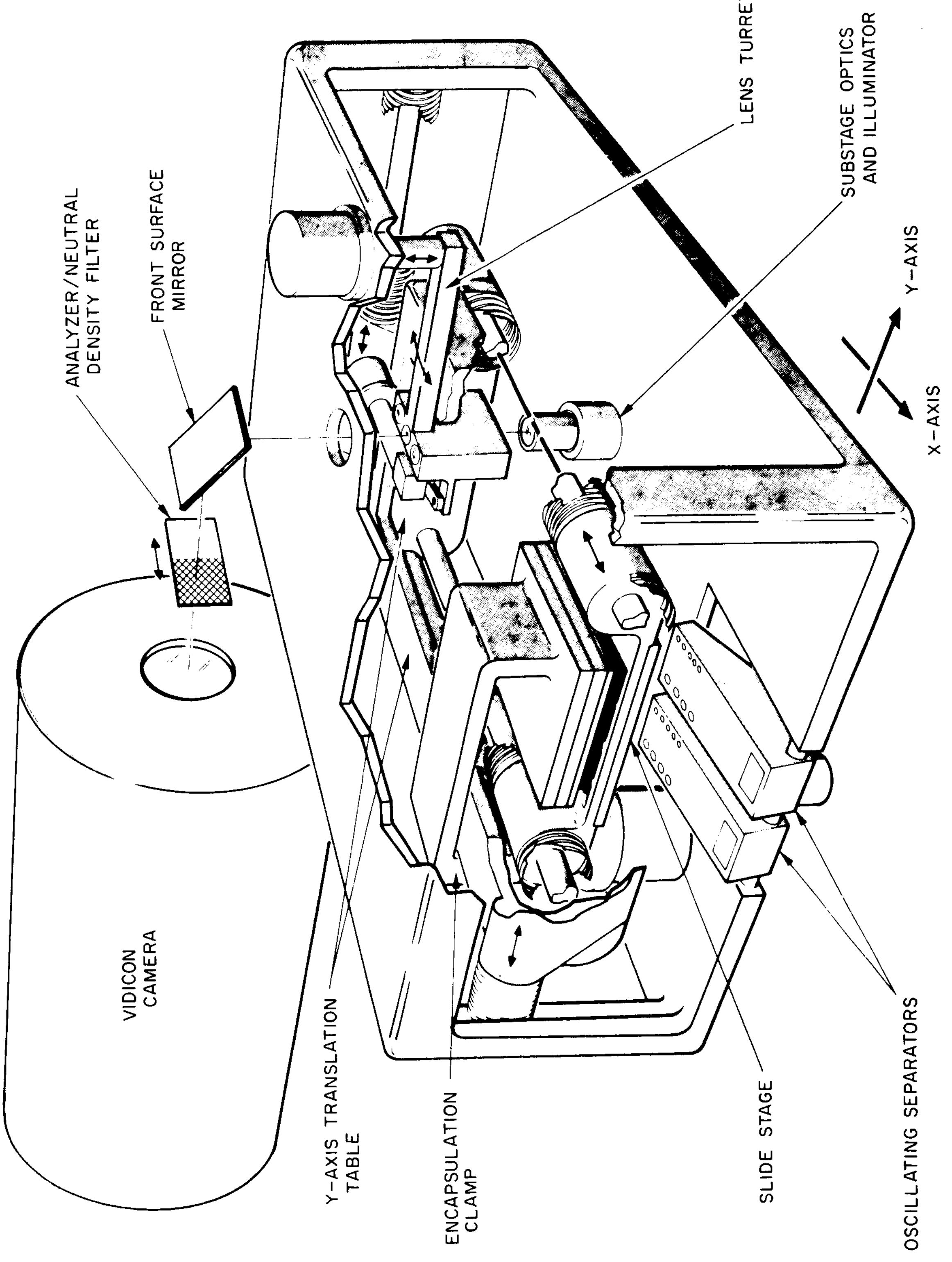

Fig. 1. Conceptual drawing of prototype

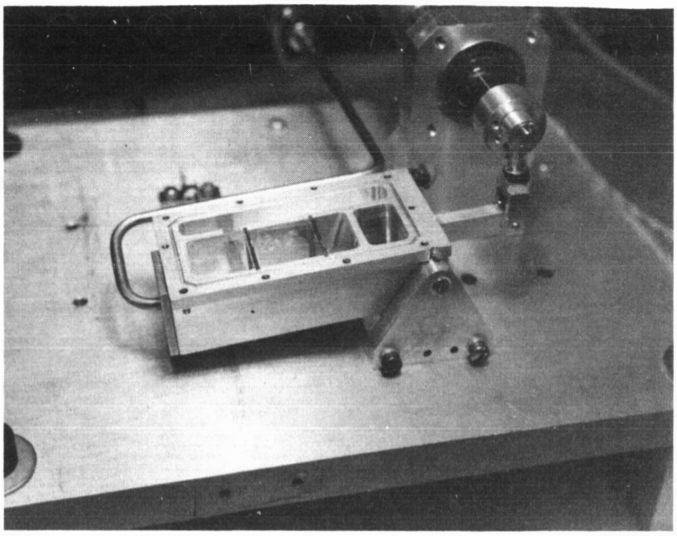

Fig. 2. Oscillating particle separator demonstration model, uncovered

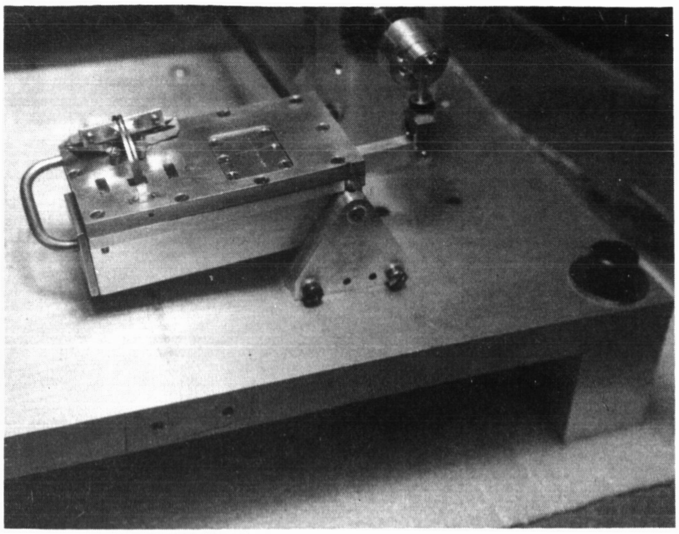

Fig. 3. Oscillating separator, with particle escape ports open

INFRARED EMISSION FROM SILICATES

NASA Work Unit 185-42-20-20-55

JPL 383-20501-2-3250

(This work unit is jointly funded under NASA Code 190-42-20-20-55. Refer to the Manned Space Science Section for the appropriate report.)

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SPECTRAL PHOTOGRAPHY
NASA Work Unit 185-42-20-27-55
JPL 383-20601-2-3250

(This work unit is jointly funded under NASA Code 190-42-03-01-55. Refer to the Manned Space Science Section for the appropriate report.)

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PLANETARY ATMOSPHERES (185-47)

AERONOMY

NASA Work Unit 185-47-01-01-55
JPL 383-70101-1-3280
C. A. Barth

OBJECTIVE

To conduct theoretical and experimental research in upper atmosphere physics. Laboratory methods include ultraviolet spectroscopy and electron paramagnetic resonance spectroscopy. Observations of the night airglow and twilight glow are conducted from the Table Mountain Observatory. The scientific planning and theoretical analysis of several ultraviolet space experiments are conducted under this task; namely, OGO-C, D, E and a continuing program of Aerobee 150's.

NIGHT AIRGLOW

The night airglow has been observed from the Table Mountain Airglow Observatory using a modern data accumulation technique. The data from a scanning spectrometer was recorded in a memory unit. Successive spectral scans were directly added in the memory to permit long observation times resulting in a greatly increased sensitivity and signal-to-noise ratio over conventional techniques. Approximately 100 hr of observing time have been used to measure Herzberg bands in the near ultraviolet portion of the night airglow spectrum, and for the first time, the night airglow spectrum has been measured from the ground in the range from 3100 A down to the 2972 A atomic oxygen line.

The same instrument has been used to measure the Herzberg bands from laboratory sources, and a direct comparison has been made of the intensity distribution of these bands in the upper atmosphere and in the laboratory. Theoretical calculations of the night airglow excitation mechanism of the Herzberg bands have also been made.

Work is going forward toward final data reduction from the laboratory measurements and preparation of a manuscript for publication.

C. A. Barth presented a paper entitled "Nitric Oxide," at the Symposium on Aeronomy at Cambridge, Massachusetts, August 1965. The printed version of the paper will appear in the proceedings of the meeting.

The EPR apparatus used for many studies under this task is being moved to a new location in preparation for a six-month experimental program under H. Ford and M. Patapoff.

MODEL ATMOSPHERES

NASA Work Unit 185-47-26-02-55 (818-01-06-70*)
JPL 383-70201-2-3250

R. A. McClatchey

OBJECTIVE

The long-term objective of the model atmospheres group is to establish the physical parameters that define a particular planetary atmosphere. This involves the use of both experimental observations and theoretical calculations. The required experimental observations include the astronomical measurement of the spectra of planet-atmosphere systems, more detailed measurement from space probes, and laboratory spectra of gases. Theoretical atmospheric models will be compared with these experimental findings and updated to agree with the most recent information.

PROGRESS SINCE JULY 1965

Theoretical work in support of a remote atmospheric temperature sounding experiment has continued. The inversion scheme described in the last semiannual report (JPL TM 33-243, Vol. I) has now been applied to the radiance data obtained from the flight of our scanning spectrometer of March 1965. As the flight was plagued with numerous engineering and calibration problems, it was apparent that the obtained radiance data would be quite inaccurate. Figure 1 shows a comparison of the measured radiance with that calculated on the basis of the temperature distribution obtained by radiosonde at the point nearest the location of the spectrometer at the time of this particular measurement. The measurement error extends from zero near 2235 cm^{-1} to about 300% near the 4.3-μ band center (2350 cm^{-1}).

A somewhat revised inversion technique was applied to these data with the resulting vertical temperature profile shown in Fig. 2. All the details of the inversion technique are indicated in Ref. 1. Maximum errors are about 20°K (about 10%) and the correct general shape of curve is obtained. It should be recognized that this 10% temperature error is obtained in spite of radiance errors as large as 300%. No further evaluation of the March 1965 flight is anticipated due to the large uncertainty in the measurement errors. A second balloon flight will take place in March 1966, so it is anticipated that we will have more data to analyze during the next period.

In addition to the temperature sounding experiment, work has continued in support of astronomical observations of infrared spectra. A computer program was developed to calculate atmospheric transmission in the 2 μ region at low resolution. Figure 3 shows a comparison of such computed transmission with observed results in the terrestrial atmosphere. Figure 4 shows similar results computed for the indicated mp products (m = amount of CO_2, and p = atmospheric pressure), and compared with the low resolution spectra obtained by Kuiper (η in Fig. 4 refers to the secant of the zenith angle). From Fig. 4 the best estimate of the mp product is 500 ±200 m-atm-mb. Analysis of high resolution spectra of Mars obtained by Schorn in the photographic infrared, suggests the amount of CO_2 is m = 72 ±12 m atm. Thus, spectroscopic observations yield surface pressures ranging from 4 to 20 mb with a value of 6 to 10 mb appearing to be the most probable. These results are documented in Ref. 2.

*Transferred to Voyager Project in FY 1966.

Within the past six months, the invention of the CO_2 laser was brought to our attention. The CO_2 laser can be made to operate on rotational lines of either the 9.4 or the 10.4 μ CO_2 bands. A small amount of effort was given to an investigation of possible atmospheric probe experiments that could be accomplished with such an instrument. The great temperature and pressure sensitivity of the absorption in a rotational line belonging to either of these bands is shown in Fig. 5. A Mars CO_2 laser experiment looks very promising and could in principle yield atmospheric temperatures near the surface and surface pressures as a function of position over the entire planet. This suggestion is written up in detail in Ref. 3. The investigation of the 9.4- and 10.4-μ CO_2 bands yielded the additional piece of information that the integrated intensities of these bands may be 10 to 20% lower than the values reported by Burch et al (Ref. 5).

An analysis of the high resolution Mars spectra obtained by Pierre Connes and Reinhard Beer in France in March 1965 is continuing. This analysis is being pursued by L. D. Kaplan. The results of his analysis are not yet definitive, and we must await additional laboratory spectra of various molecules. The contract, which was let last May to D. Burch of Aeronutronic, was fulfilled, and the detailed results of the laboratory spectra of the 1.6 μ bands of CO_2 are now available. These results are documented in Ref. 4. We are currently negotiating another contract (probably with D. Burch of Aeronutronic) in order to obtain laboratory spectra of various gases thought to be possible Martian atmosphere constituents. It is hoped that this contract will commence within the next 2 months.

Calculations have been made for the 2-μ region of Venus and compared with the experimental observations obtained by Kuiper. The results indicate that the simple model of a reflecting layer in the Cytherean atmosphere does not adequately explain the experimental data. Detailed analyses of the 1.05-μ CO_2 bands of Venus obtained by R. Schorn is in progress and appears to yield additional inconsistent results. It seems likely that the inconsistency in both the 1.05- and 2-μ results arises from the neglect of scattering in the Cytherean atmosphere.

A computer program is being developed to handle the problem of combined absorption and scattering processes in a planetary atmosphere. This program will be initially applied to the problem of the breakdown of thermodynamic equilibrium with respect to the absorption of solar radiation in the 4.3-μ CO_2 band. The program should then have application in both the calculation of radiative equilibrium vertical temperature profiles for Mars and in the investigation of the effects of combined absorption and scattering in the Cytherean atmosphere.

PROPOSED WORK FOR JANUARY-JULY 1966

In addition to the obvious extension of the work indicated in the above sections, the following specific tasks will be undertaken in order to work toward the above-mentioned long term goals:

1. Analyze data to be obtained from balloon flight of spectrometer in March 1966. An entirely new method similar to that used by D. Wark of the U.S. Weather Bureau (see Ref. 6) will be investigated. Dr. Wark's method utilizes empirical atmospheric data to a large extent and so should be capable of better results for

the terrestrial atmosphere. His method, however, will not be directly applicable for data eventually obtained from a Mars mission.

2. Evaluate the results of the Mariner occultation experiment and incorporate the most recent infrared spectra of Mars into the "best" Martian atmosphere density profile for engineering use.

3. Calculate spectral absorption of the 1.6- and the 1.05-μ CO_2 bands for comparison with the laboratory data of D. Burch et al.

4. Complete development of the computer program to handle the problem of combined absorption and scattering and apply this to the 4.3-μ CO_2 band in both the terrestrial atmosphere and the Martian atmosphere.

References 1-4 are direct results of the work undertaken by the Model Atmospheres Group during the past 6 months. In addition to these, Ref. 1 and 3 were presented orally by R. A. McClatchey at the International Symposium on Electromagnetic Sensing of the Earth from Satellites held in Miami Beach from November 22-24. A paper entitled "Interpretation of the Spectrum of Mars in the 2 Micron Region" will be presented by L. D. Gray at the January 1966 meeting of the American Institute of Aeronautics and Astronautics in New York City.

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2. Gray, L. D., "Transmission of the Atmosphere of Mars in the Region of 2 Microns," to be published in Icarus.

3. McClatchey, R. A., and Norton, R. H., "Atmospheric Sensing with CO_2 Lasers," to be published in the proceedings of the Internat. Symp. on EM Sensing of the Earth from Satellites.

4. Burch, D. E., Gryvnak, D. A., and Patty, R. R., "Absorption by CO_2 between 5400 and 6600 cm^{-1}," Aeronutronic Publication No. U-3201, August 1965.

5. Burch, D. E., et al, "Infrared Absorption by Carbon Dioxide, Water Vapor, and Minor Atmospheric Constituents," AFCRL-62-698, July 1962.

6. Wark, D. Q., et al, "Indirect Measurements of Atmospheric Temperature Profiles from Satellites," submitted for publication to the Monthly Weather Review.

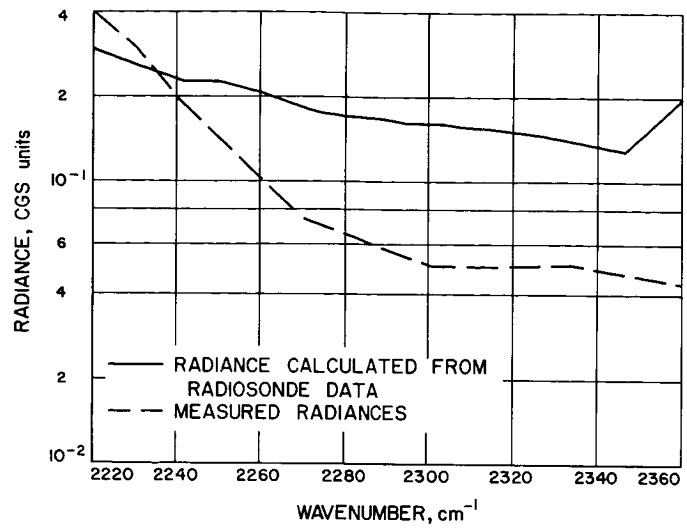


Fig. 1. Comparison of measured and theoretical radiances

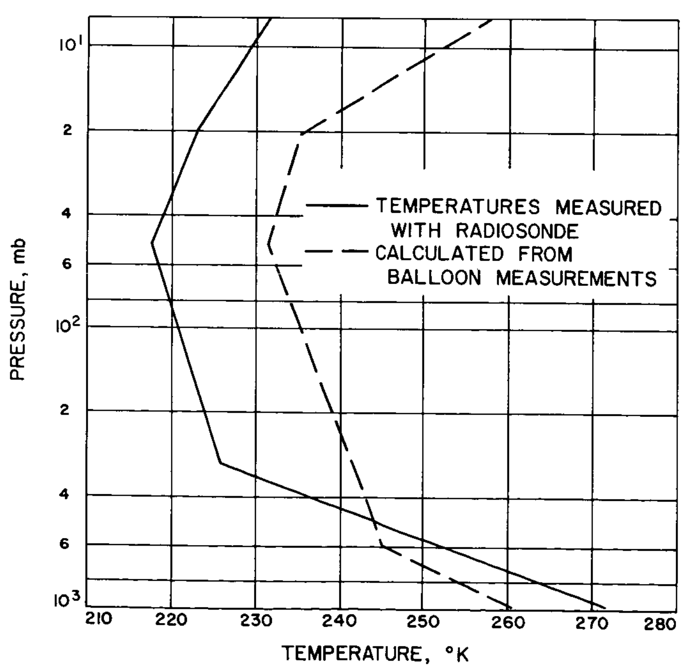


Fig. 2. Comparison of measured temperatures with those calculated from experimental radiance values

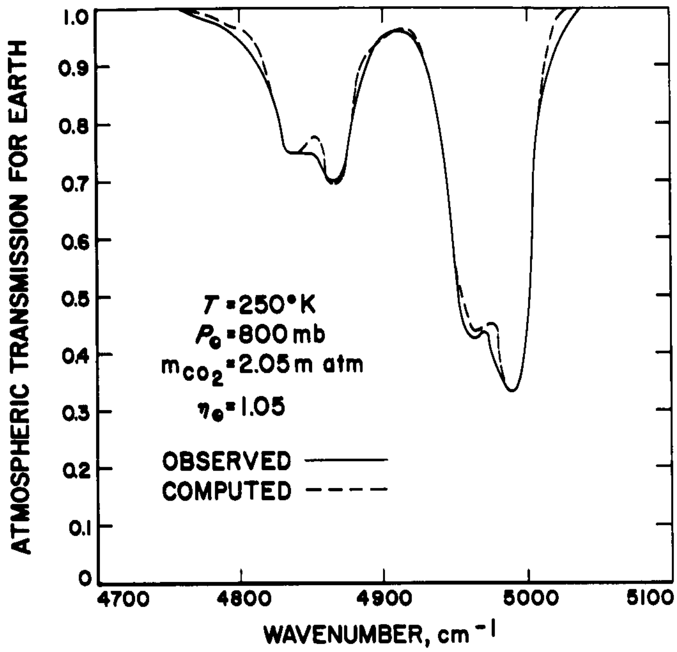


Fig. 3. Comparison of theoretical transmission through the Earth's atmosphere with that of G. Kniper

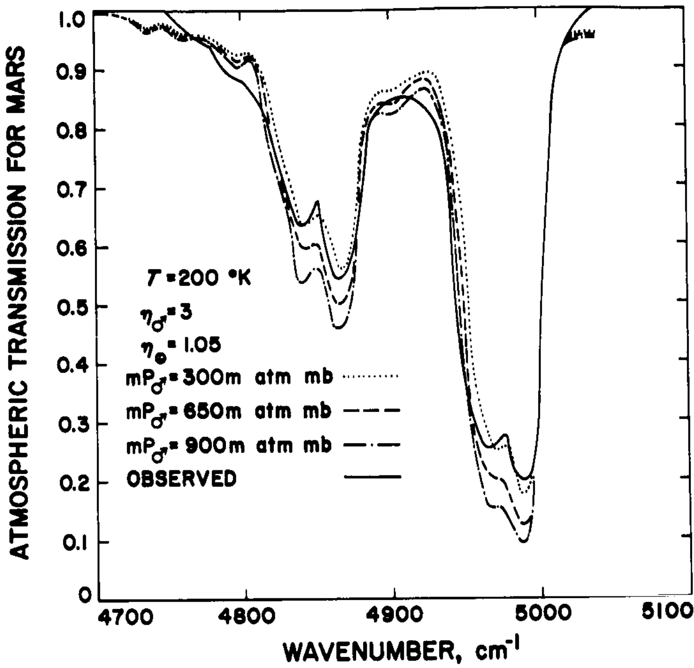
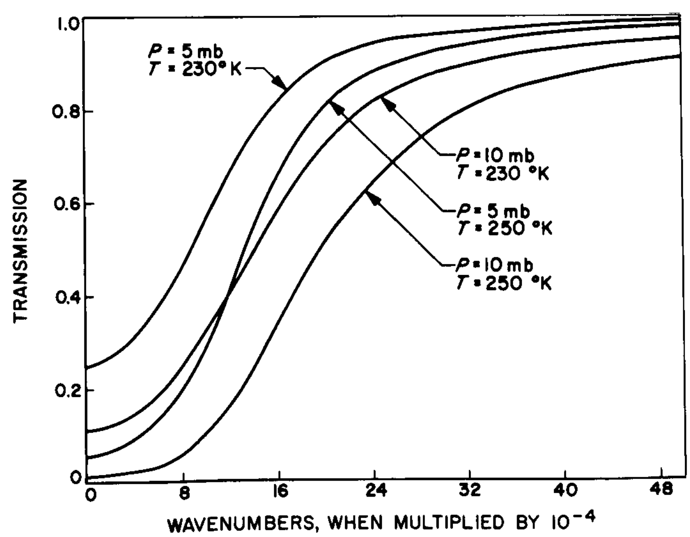


Fig. 4. Comparison of theoretical transmission through the Martian atmosphere with that of G. Kuiper

Fig. 5. Calculated transmission for assumed Martian atmosphere conditions



ADVANCED TECHNICAL DEVELOPMENT (186)

PLANETARY QUARANTINE STERILIZATION (186-58)

ACTUATOR STERILIZATION

NASA Work Unit 186-58-02-01-55
JPL 384-82801-2-3440
G. S. Perkins

OBJECTIVE

The objective of this task is to provide sterilizable spacecraft control actuators and components thereof for future space exploration programs.

DETENTING MOTOR

This development was undertaken to provide a prime mover for advanced types of spacecraft hinge actuators. Actuators of this type may be required on the Voyager spacecraft or capsule.

The development of a sterilizable detenting servomotor was performed by Vernatron Corporation following direction from JPL. The development has been completed and was successful.

The final report will be completed during the third quarter of FY 1966.

JET VANE ACTUATOR

An advanced type of jet vane actuator using typical autopilot performance requirements is under development at Aeroflex Laboratory in Plainview, Long Island, New York. This actuator when completed will have eliminated ball bearings and feedback potentiometers and instead will use flexture-type bearings and will have a linear curve of position versus coil current for servo feedback purposes. The contract with Aeroflex was recently revised to develop flexture-type bearings before proceeding with the remainder of the task. Work has been resumed.

A schedule outlining the activity called for by the statement of work has been submitted to JPL. The major effort will be directed toward the development of the flexural bearing. An approach for the solution of this problem has been established.

After solution of the bearing problem, a breadboard model of the actuator will be assembled for evaluation.

DUAL POTENTIOMETER

A dual potentiometer is required for use in the antenna actuator being developed in NASA Work Unit 186-68-02-03. Figure 1 shows the mechanical and electrical requirements for the potentiometer. The internal detail is to be furnished by the vendor. The potentiometer is to be in two parts: a card and a wiper assembly. The use of slip rings for wiper takeoff is optional. The potentiometer will be mounted directly on the output shaft on the actuator. The entire assembly will then be subjected to sterilization environments.

Negotiations for procurement of the potentiometer are nearing completion. It is expected an order may be placed within two weeks.

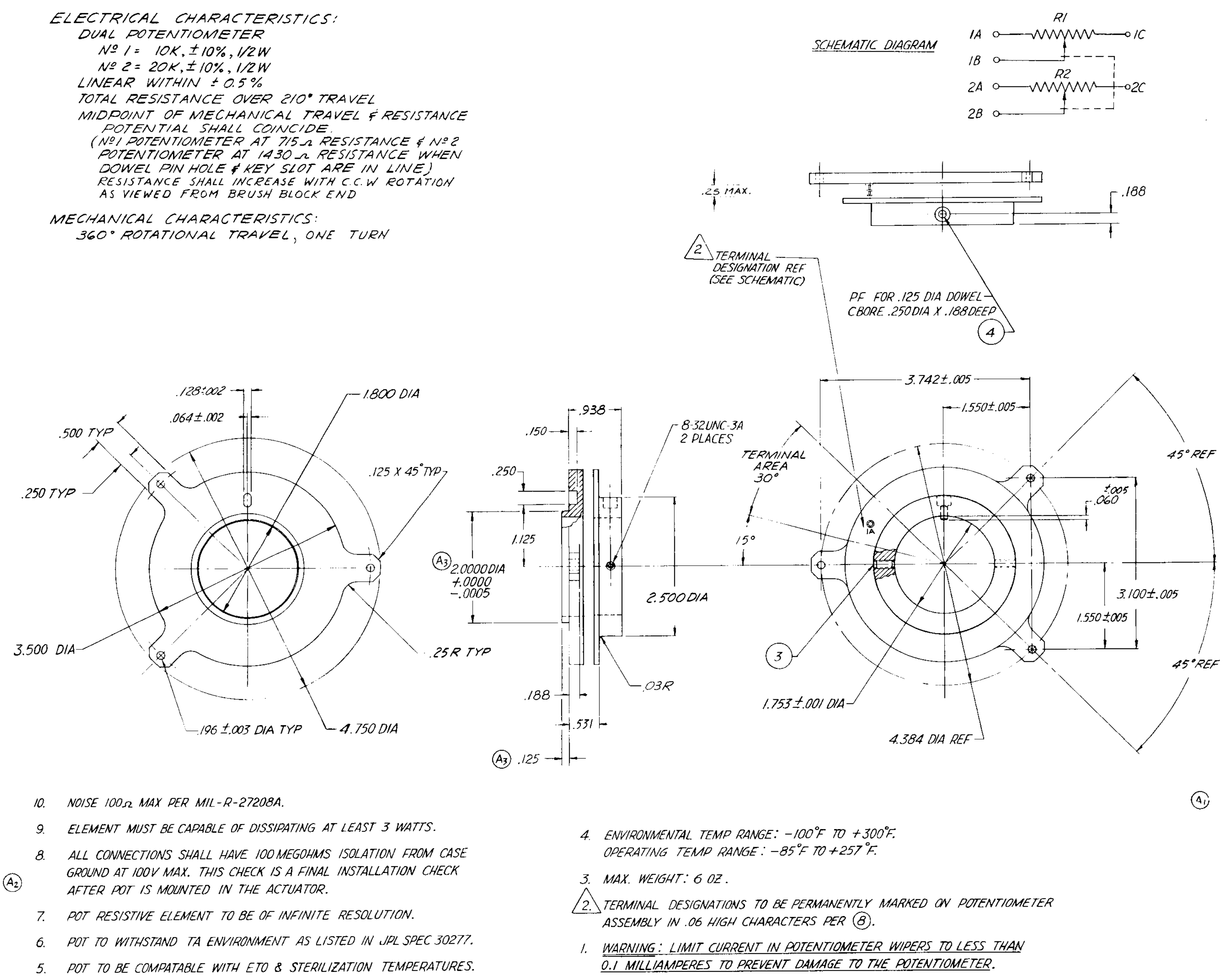


Fig. 1. Dual-potentiometer assembly

HIGH-TEMPERATURE PHOTOCATHODE IMAGE DISSECTOR

NASA Work Unit 186-58-02-02-55
JPL 384-82501-2-3440

E. S. Davis

OBJECTIVE

The objective of this task is to make available a flightworthy electrostatic image dissector capable of withstanding the heat sterilization and ethylene oxide decontamination requirements.

PROGRESS OF THE STERILIZABLE IMAGE DISSECTOR CONTRACT

A program with this objective was started with CBS Laboratories in June 1964. A two-stage approach based on first developing a bi-alkali photomultiplier not requiring cesium and, second, transferring these processing techniques to the image dissector was established.

The first stage was essentially completed in the last six-month period. Early in this period CBS fabricated several photomultipliers and trained another operator in the bi-alkali processing techniques. Tubes fabricated by the new operator had good photoresponse which responded well to heat sterilization. However, the effect of sterilization on gain in these tubes can best be characterized as erratic. Although the gain after six sterilization cycles is in every case somewhat improved, the intermediate variations are between a factor of 1.5 and 2.3 peak to minimum. The contractor feels that this stability problem was brought on by the introduction of the new operator. Although tubes are made to strict process specifications, judgement plays a large part in terminating many steps in the activation process. It appears that operator skill might play a large part in building sterilizable image dissectors.

This experience with a change in operator makes meeting the heat sterilization type approval test at 145°C for 36 hr look somewhat marginal. This experience and timing, coupled with other factors such as the erratic performance of the gain on two experimental image dissectors and other photomultipliers subject to six heat cycles made adoption of the Voyager sterilization test requirements look desirable. The changes to the contract sterilization procedure are summarized in Table 1.

CBS has also added a manual monochrometer to their capital equipment and it has been discovered that all of the early spectral response data was in error. Figure 1 shows the absolute spectral response of a typical photomultiplier tube. Careful scrutiny of the curves and the accompanying table of photoresponse data indicates that the reduction in the relative red sensitivity is not the cause of the reduction of the photoresponse as originally concluded from early spectral response data. The relative sensitivity at 5,000 A only drops by about 10% on each of the first two cycles and then remains constant for subsequent cycles.

CBS is now preparing to cycle the image dissector tubes on this contract through the sterilization cycle, which will conclude this contract.

Table 1. Sterilization procedure

	Time, hr	Temperature	Humidity	Cycles
Ethylene oxide decontamination				
Old contract	32	110° ± 10°F	35 to 90%	1
Voyager (Present contract)	24	50° ± 3°C	35 (+15, -5)%	6
Heat sterilization				
Old contract	36	145° ± 2°C	DRY N_2	6
Voyager (Present contract)	92	135° ± 2°C	DRY N_2	6

PARTICIPATION IN THE NASA SPACECRAFT STERILIZATION CONFERENCE

E. S. Davis co-authored a paper with J. C. Nicklas, W. E. Bachman, E. F. Koch, and R. J. Mankovitz, presented at the National Conference on Spacecraft Sterilization, entitled "Guidance and Control System Sterilization," which briefly reviews this program as well as other guidance and control sterilization programs. CBS Laboratories sponsored the attendance of the project engineer, F. Misso, on the above contract at this conference.

FUTURE ACTIVITIES

A statement of work has been written for further improvement of the sterilizable image dissector and this contract should start in the 3rd quarter of FY 1966. The statement of work provides for: (1) improvement in processing techniques to improve cathode uniformity and gain stability, (2) fabrication of tubes for testing, (3) sterilization testing of two tubes at type approval level and two tubes at flight acceptance level, and (4) life testing of two tubes at room temperature with various input illumination levels.

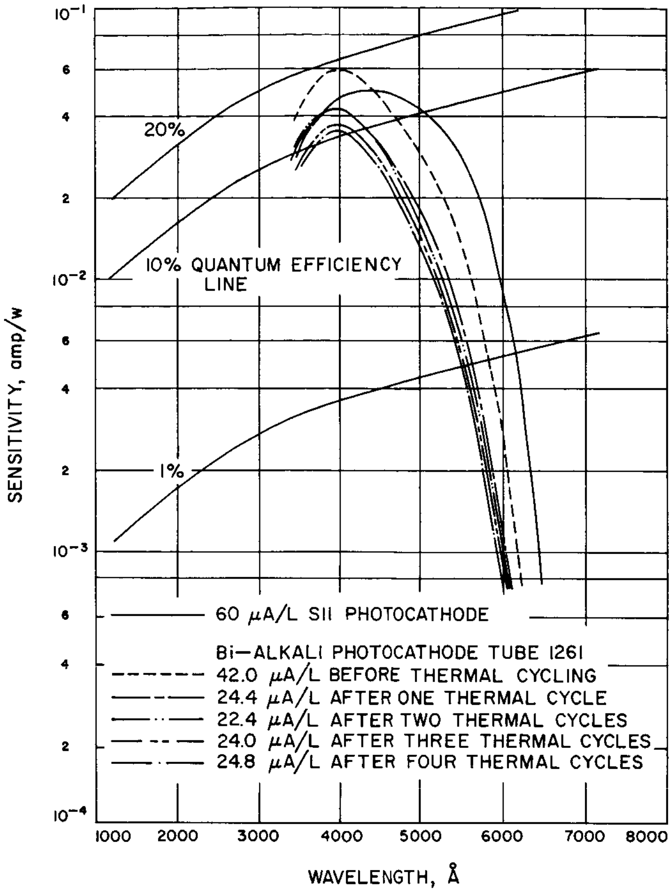


Fig. 1. Photocathode response curves

INERTIAL SENSORS STERILIZATION

NASA Work Unit 186-58-02-03-55
JPL 384-82701-2-3440

P. J. Hand

OBJECTIVE

The objective of this work unit is to develop thermal sterilization and gas sterilization capability into the newer designs of inertial sensors, which have potential application in advanced spacecraft and capsule control systems. Included in the category of inertial sensors have been the needs for both long life gyros and accelerometers.

GYRO DEVELOPMENT

It is the intent of this program to develop the Honeywell GG159C gas bearing gyro to be capable of surviving six thermal sterilization cycles without catastrophic failure or significant degradation of performance.

The first gyro has been delivered to JPL for continued evaluation of the effect of additional sterilization cycles. This test program at JPL has shown that the g-sensitive drift terms on this gyro were continuing to change during the early testing, while the g-insensitive drift rate appears to have stabilized. These trends can be seen on the data plot shown in Fig. 1. (This chart is a continuation of the chart shown on p. 97 of the last six-month report, JPL Technical Memorandum No. 33-243, Volume I.) Figure 1 is actually a smoothed curve of data taken at JPL during several months of testing. The spacing between data points does not indicate equal time intervals. The types of tests or environments involved are described on the lines above the points.

Additional hot and cold cycling has been performed on this unit during the JPL tests. The cold soak periods, wherein the gyro is cooled to 32°F for 24 hr, seem to have a stabilizing effect on the g-sensitive drift parameters. The most recent efforts on this gyro have been another complete sterilization using the recently adopted procedure of 6 cycles of 135°C for 53 hr with a controlled rate of temperature rise and fall of 19°C per hr. No performance data is yet available from this operation although it is known that the gyro is still in operating condition.

In addition to the performance data shown in Fig. 1 the gyro spin motor is demonstrating anomalous behavior during startup. The problem manifests itself as an inability to reach synchronous speed if the gyro is above 160°F. The normal operating temperature is 180°F. To overcome this condition and still continue to obtain data, the startup procedure has been modified so as to start the motor from room ambient temperature. When proper synchronous speed has been reached the temperature controller is then energized and the gyro brought to 180°F. It is presently believed that this malfunction was caused by damage to the rotor during one of the buildup cycles and is not a result of thermal sterilization.

This gyro development effort is being continued with the procurement of a second sterilizable gyro which incorporates all modifications developed to date. This instrument is now in the final stages of test and is due at JPL early in 1966.

ACCELEROMETER DEVELOPMENT

The goal of this effort is to develop a high-accuracy guidance type accelerometer capable of withstanding six thermal sterilization cycles without either catastrophic failure or significant performance degradation.

It is planned that this development shall start from a known design base and proceed through a series of design evolutions to the final goal. The base chosen for this effort is the Bell Aerosystems linear force balance accelerometer. The original form of this instrument was used as the guidance accelerometer on the Sergeant guided missile system. A further advanced design combined with a reduction in size was used as the midcourse shutoff accelerometer on the Ranger and Mariner R series of spacecraft as well as several space launch vehicles.

The most recent design of this basic instrument, known as the model VII, is to be the starting point for the design of the sterilizable accelerometer. The same concepts proven in past designs are used in this instrument, with the principal differences being a further reduction in size and weight.

To verify that this design was a proper starting point, two standard model VII accelerometers were purchased for evaluation at JPL. Data is being obtained on their long- and short-term stabilities, their performance under typical spacecraft vibration and shock environments, and finally their ability to operate and survive under progressively higher temperature.

The first unit placed under test was rejected and returned to the manufacturer after about one month of testing, due to a large drift rate of the bias (null offset) parameter.

The second unit was subjected to similar long- and short-term stability tests. The performance of the bias error parameters, while not as stable as the Ranger type of accelerometers, did settle out enough to enable vibration testing to proceed. The vibration environment used was the typical Ranger flight acceptance complex wave vibration. The instrument passed the FA vibration but suffered a catastrophic failure of the suspension during a subsequent type approval vibration test. The TA vibration levels are severe, being on the order of 18 g rms, but all units considered as flight capable must be able to pass this environment.

The first unit rejected has since been rebuilt and returned to JPL for testing. This accelerometer has successfully passed the initial testing phase, has been temperature cycled to 180°F, and has had a long term stability test of 725 hr without significant deviations.

The chart shown in Fig. 2 demonstrates the performance obtained from this instrument during the constant-temperature, constant-operation run. This data is indicative of the best possible performance as the temperature was maintained at 99.5°F within 0.1°F for the entire period. The bias parameter was measured at the zero-g input condition and shows a mean bias of -140.6 micro g with a standard deviation, one sigma, of 11.3 micro g for the entire 725-hr period. The scale factor shown is the mean value of the positive and negative one g inputs. The data shown has a mean of 1.004158 v per g and a standard deviation, one sigma, of 0.0021% for the run.

The next phase of testing will be environmental, with vibration coming first, followed by shock testing. The second unit is due to be returned to JPL early in 1966 for further testing.

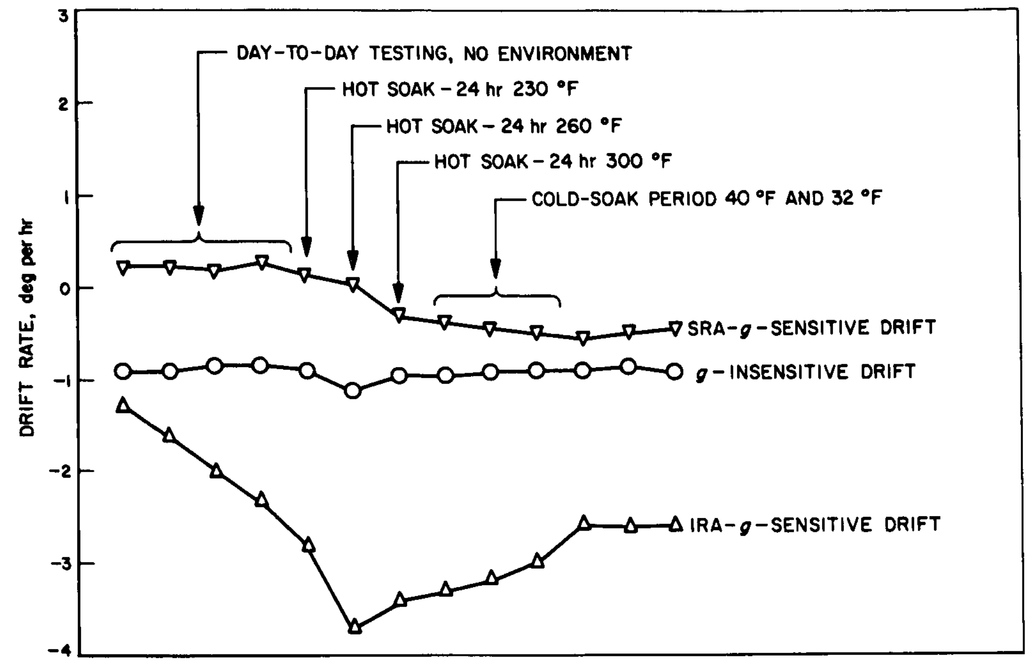


Fig. 1. Drift performance, gas bearing gyro

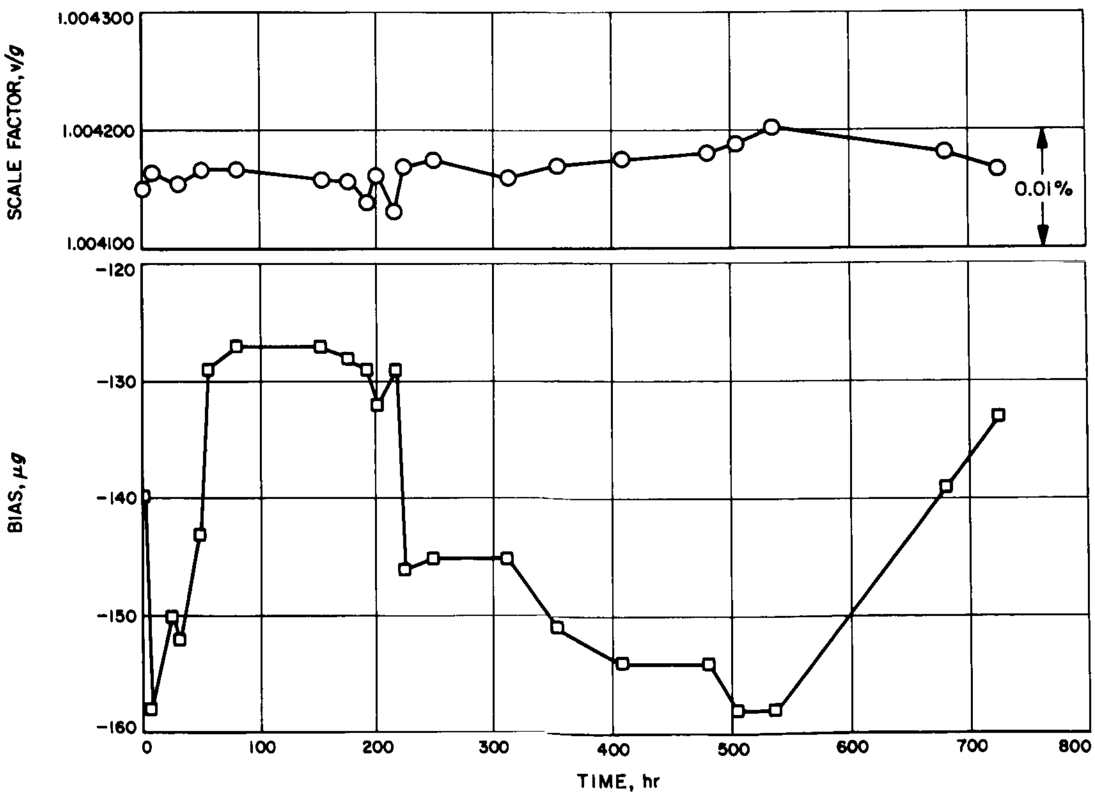


Fig. 2. Stability at constant temperature (99.5 ± 10°F)

STERILIZABLE PHOTOCONDUCTIVE DETECTORS
NASA Work Unit 186-58-02-04-55
JPL 384-81401-2-3440
D. G. Carpenter

OBJECTIVE

The primary purpose of this work unit is to develop qualified detectors, either by test and evaluation of presently available devices or fabrication and qualification of special photoconductors built to JPL derived specifications.

PRESENT ACTIVITIES

A contribution was made to the paper, "Guidance and Control System Sterilization," presented at the First Annual National Conference on Spacecraft Sterilization Technology.

A series of sterilization cycles (135°C for 62 hr/cycle) have been completed on a selection of 13 cadmium sulfide photoconductors. Eleven cells were of the sintered form, two were vacuum-deposited.

A total of six cycles was run. Five cells successfully underwent six complete sterilization cycles with the only effect being a limited change in resistance at any given light level. The other eight cells exhibited identical failure modes, that of very low resistance, and no sensitivity after varying numbers of sterilization cycles. Two of the five good cells were the vacuum-deposited cells produced by Autonetics under contract to JPL.

The conclusions drawn from these tests are that presently available cadmium sulfide photoconductors which are made by the sintered process are <u>not</u> sterilizable. It appears from data to date that vacuum-deposited cadmium sulfide photoconductors are sterilizable.

Additional tests will be conducted to substantiate these conclusions.

FUTURE ACTIVITIES

Working in connection with NASA Work Unit 186-68-02-19, Photodetector Performance Improvement, specifications will be formulated with sterilizability as one of the requirements. From these specifications a contract will be let to an as yet unknown contractor for the fabrication of sterilizable cadmium sulfide photoconductors meeting JPL specifications.

STERILIZABLE CAPSULE CONTROL SYSTEM

NASA Work Unit 186-58-02-05-55
JPL 384-80301-2-3440

R. Mankovitz

OBJECTIVE

The objectives of a systems effort in sterilization investigations are: (1) to define the components required for guidance-and-control subsystems on landing capsules, (2) to establish new subsystem designs when current mechanizations cannot be sterilized, (3) to study the compatibility of component sterilization methods with systems-level sterilization techniques, and (4) to establish testing philosophies and procedures for final sytems tests. Since the component investigations are dependent upon objective (1), this task must be undertaken first. The remaining objectives have strong interrelations with the component programs and are being studied simultaneously.

REQUIRED COMPONENTS

The determination of necessary components for capsule control systems is made by studying previous capsule investigations and tabulating the types of devices required. Where this information is unavailable, projections are made as to the types of subsystems that may fulfill mission requirements. In each case, since a specific set of mission requirements is unavailable, it is impossible to completely specify the components that will be required. One can be somewhat more general, however, and say that high-quality gyroscopes and accelerometers; Sun sensors; possibly a star or planet sensor; and actuators for attitude control, autopilot, and articulating devices will be required.

SUBSYSTEM REDESIGN

In present techniques of mechanizing some control systems, the circuits use large-value capacitors (some in excess of 4000 μf). Since this requires the use of wet-slug-type or wet-foil-type capacitors, it is possible that these components will not survive thermal sterilization.

Presently, a Mariner C attitude control system electronics package is being subjected to thermal sterilization testing, to determine component degradation and other possible problem areas.

Anticipating capacitor and transformer problems, other circuit mechanizations not requiring these components have been considered. Among the mechanizations for timing circuits is a digital technique utilizing a counter and pulse generator. This mechanization decreases the size of the required capacitor by a factor corresponding to the number of counter stages. Because of the high reliability of silicon semiconductors, the reliability of this type of circuit may be considerably greater than that of the conventional mechanization. Other special circuits have been studied which will eliminate the use of transformers and large-value capacitors in attitude-control and autopilot systems. It is planned to breadboard the circuits considered and subject them to thermal sterilization followed by functional testing.

COMPATIBILITY OF STERILIZATION METHODS

Part of the systems investigation is directed toward ensuring that the systems sterilization requirements are compatible with the component tolerance. As an example, consider two devices. A star tracker is most critical with the high-heat short-time sterilization cycle, and the Sun sensors are most critical with the low-heat longer-time cycle. The systems investigators must be aware of this type of component incompatibility and must make appropriate considerations in the subsystem mechanization. The solution may be either to increase component tolerance or to modify the systems design concept. This same problem arises in the overall sterilization of the capsule. In this investigation the component tolerances are being tabulated and inspected for conflicts.

TESTING PHILOSOPHY

In addition to the components problems that have to be solved, an overall systems testing philosophy must be established. The factors involved in making a decision for employing subsystem presterilization tests coupled with a high-confidence level versus poststerilization systems-level testing of critical functions is being explored. It is probably possible to obtain the necessarily high-confidence level in guidance-and control subsystems by thorough testing of several engineering evaluation models of flight hardware both before and after sterilization. There still remains a basic flaw in eliminating a final poststerilization systems test. There has been no check of the interface connections between the individual subassemblies and between the control systems and other systems. To preserve overall capsule reliability, verification of the interface integrity is imperative. Therefore, functions which must be poststerilization-tested are those which maximize the verification of the interfaces. For example, a function which would not have to be tested is one where the input and output are monitored in the same subassembly, e. g. , the continuity between an input to an attitude-control amplifier and its output. A function, such as generating a signal in a star sensor and monitoring its effect elsewhere in the system, would be a necessary poststerilization test, since it would verify many interface connections.

Consideration is being given not only to subsystem testing but also to capsule-system testing. Since final sterilization will probably be done on a capsule-system basis, all final testing would then necessarily be at a capsule-system level. At this stage of the investigations it seems that the best approach would lie somewhere between the two extremes. Establishing a high confidence level in subsystem performance after sterilization would be desirable. In addition, certain system-level interface-verification tests will probably be necessary. Further work on this subject will hopefully indicate the best choice.

REPORTS AVAILABLE

A JPL internal document on sterilization of capsule control systems contains details of several circuit mechanizations as discussed under Subsystem Redesign. In addition, a possible system functional test method is investigated.

Parts of this document were incorporated into a paper delivered at the First Annual National Conference on Spacecraft Sterilization Technology.

SPACECRAFT DIGITAL MAGNETIC TAPE RECORDER STERILIZATION
NASA Work Unit 186-58-03-01-55
JPL 384-85601-2-3340
W. Arens

OBJECTIVE

The objective of this task is to define and solve all of the problems associated with the heat sterilization and checmical decontamination of a typical spacecraft magnetic tape recorder.

GENERAL BACKGROUND

During the previous reporting period (January 1 to June 30, 1965), a Mariner IV type of transport sterilization unit was subjected to the specified sterilization testing cycle (three 36-hr periods at 145°C). After a brief period of apparently normal operation subsequent to sterilization, the unit was opened, and observations were made on the condition of components and the existence of obvious contamination. Samples of some of the deterioration products were submitted to chemical analysis, and the results were evaluated.

Following examination of the transport, a life test program was undertaken. The test was aborted after ten days, primarily because of capstan bearing failure. It was then planned to disassemble the unit for a complete investigation and analysis of subassemblies and components to determine the nature and causes of failure and contamination; and to investigate areas of component incompatibility. Some delay in this program has resulted because of lack of time, personnel, and priority.

ACTIVITIES DURING REPORT PERIOD

During this report period, a program of evaluation and analysis of each of the thirty or so component materials of the sterilized Mariner IV type transport was undertaken. The unit was completely disassembled in a clean room environment. Metrology examination of all critical rotating hardware has also been undertaken and is in process to determine if any dimensional changes have resulted from the sterilization environment. Capstan bearings are being analyzed to determine the characteristics of failure. The primary cause of bearing failure has been established as breakdown of lubrication; however, it remains to be determined whether such deterioration was due to lubricant dissipation, contamination of lubricant, or both (Fig. 1).

Several polymers and other nonmetallic compounds (in addition to those discussed last period) used in this recorder have been submitted for chemical analysis to determine their contribution, if any, to corrosion and contamination. It has been established that at least one item, the magnetic tape binder, which is a polyvinylchloride polyvinyl acetate compound, decomposes at elevated test temperatures releasing HCL which is highly corrosive to metals reacting to give hydrogen gas and metallic chlorides. Magnesium, the material of the transport face plate, is particularly susceptible to attack by HCL which probably accounts for the severe corrosion deposits formed thereon and on other metallic components (Fig. 2).

Materials used in motor and magnetic head fabrication are also to be evaluated. Although they have apparently survived the sterilization cycle, the extent of any minor degradation that might mean imminent failure is not known. Also, materials compatibility must be determined.

A paper entitled "Sterilizable Communication and Data Handling Systems," summarizing the tape recorder sterilization program to date, was presented to the NASA National Conference on Spacecraft Sterilization Technology at California Institute of Technology in November 1965.

FUTURE ACTIVITIES PLANNED

Work will continue on the investigation and evaluation of materials used in the recorder. It is expected that as the results of such analyses become available, areas for further investigation will be apparent. Such areas already apparent are: bearing lubricants, tape binders, epoxies and cements, and end-of-tape sensing devices. Concentrated efforts will be made to pursue these investigations.

A final report will be prepared which will cover in detail all observations and findings relative to the investigation of the subject recorder. Conclusions will be drawn and recommendations made.

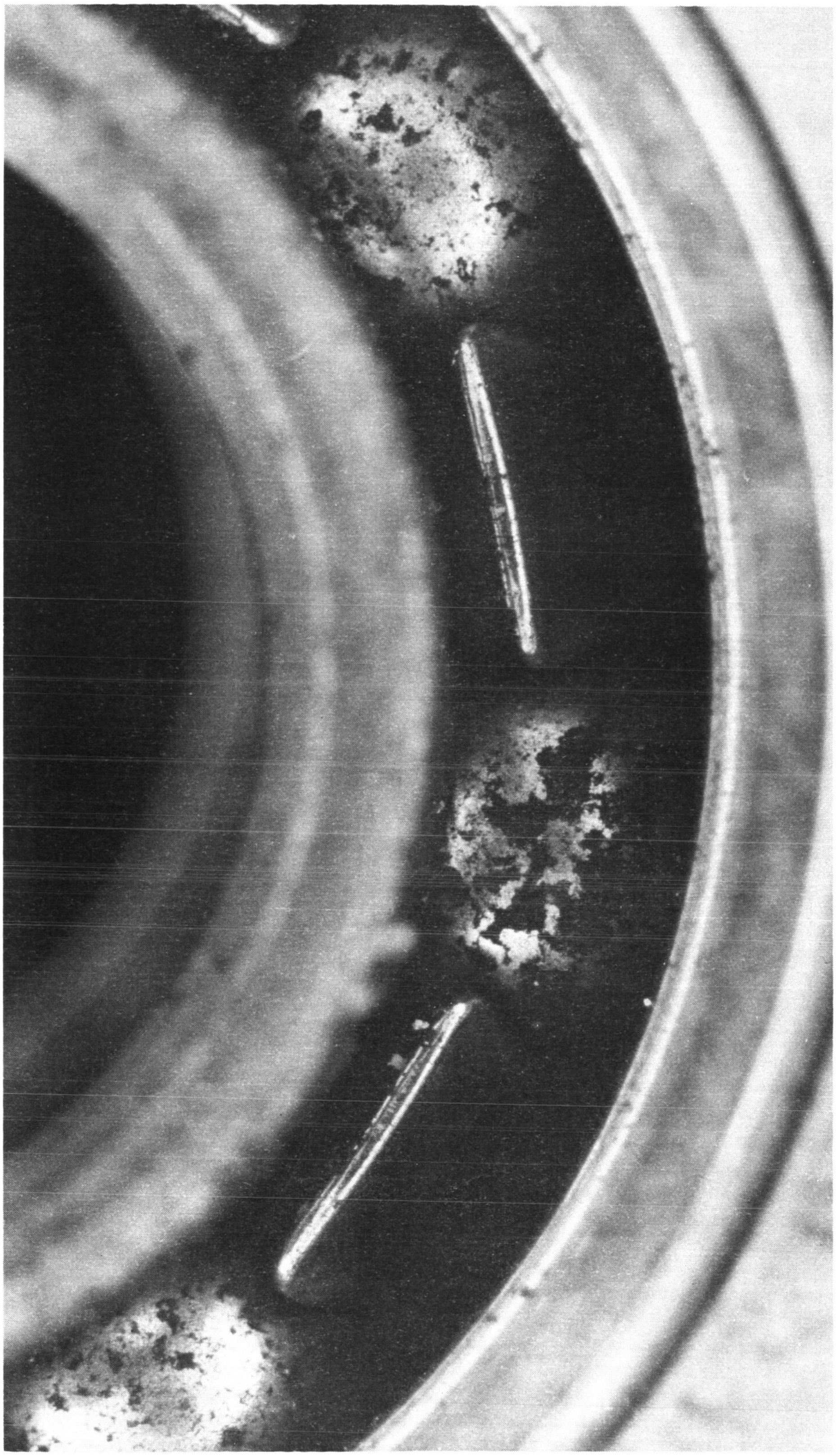


Fig. 1. Ball-bearing corrosion

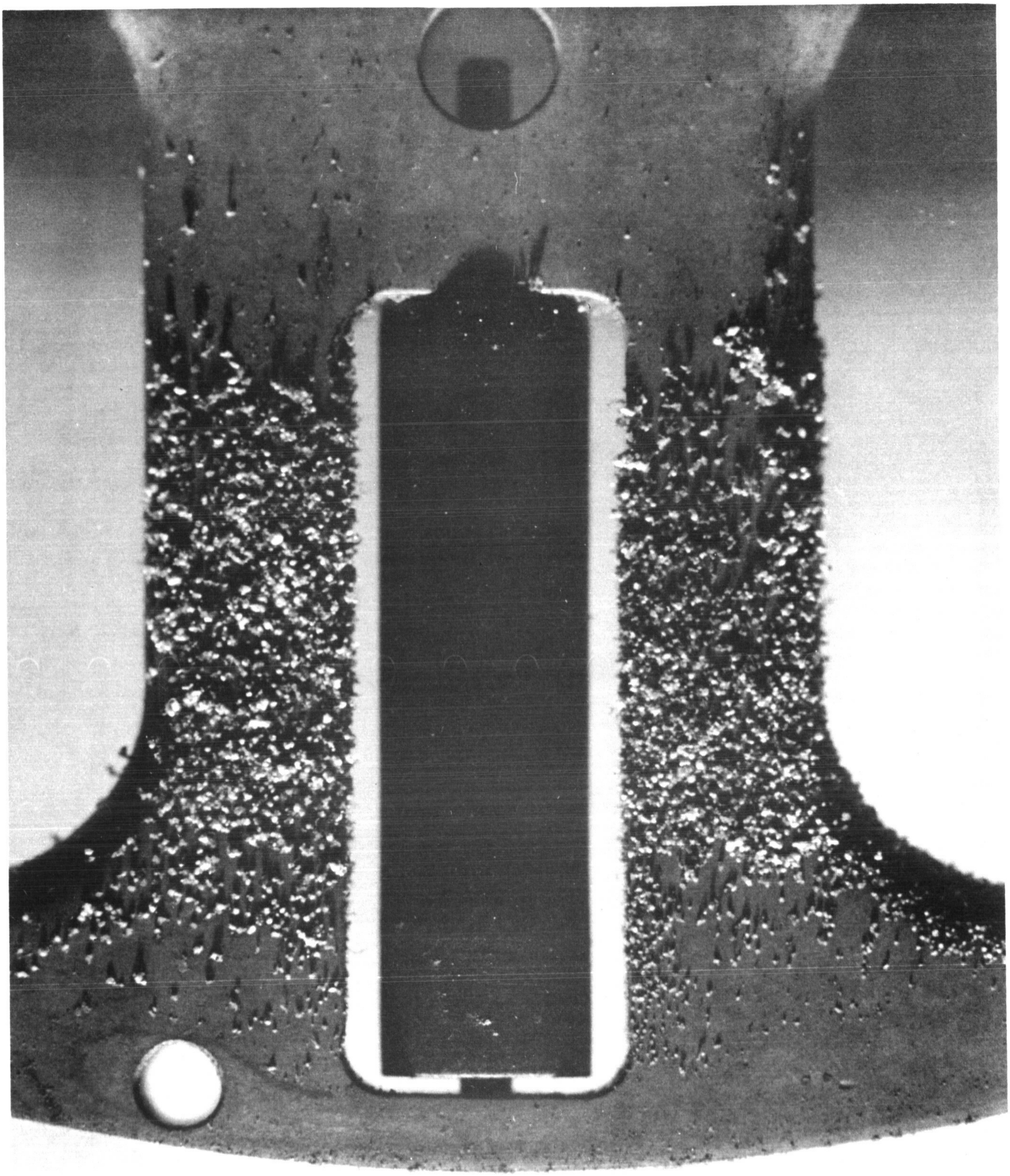


Fig. 2. Tape pack deposits

MINIATURE ELECTRO-OPTICAL IMAGE DETECTOR STERILIZATION

NASA Work Unit 186-58-06-03-55
JPL 384-84301-2-3230

L. R. Baker

OBJECTIVE

The present technology related to vidicons for space imaging system application has not made available vidicons capable of meeting present sterilization requirements. Additionally, it is logical to assume that any sterilizable component would find application in a high-impact environment. Therefore, the purpose of the proposed program is to develop a sterilizable vidicon capable of withstanding the high-g shock loads.

The proposed program is to be a continuation of an effort presently being done by RCA under JPL Contract No. 950985. Funding under the FY 1965 program will provide a minimal effort resulting in less than adequate testing and too few deliverable items for thorough evaluation. The FY 1966 program augments the FY 1965 funding and brings the total effort to a level of high confidence by increased tests and evaluation.

PROGRESS DURING REPORTING PERIOD

The contract was initiated on May 21, 1965, so this report will cover all the work done so far. The program was logically divided into two phases to run concurrently. Phase I was the development of the sterilizable photoconductor, and phase II was the development of the complete ceramic vidicon incorporating the sterilizable photoconductor.

Phase I — A total of 29 type 7735A vidicons was made incorporating the sterilizable photoconductor. The tubes were operated in a test set to determine the operating characteristics and then passed through the entire sterilization compatibility test according to JPL Specifications XSO-30275-TST-A and GMO-50198-ETS. Of the 29 tubes, 25 were completely and satisfactorily sterilized. Three of the 29 tubes failed due to overheating in the oven. The temperature of the oven accidentally went above the 155 °C melting point of indium, which is used to seal the quartz faceplate to the tube envelope. One tube was not sterilized because of extremely poor image quality. The main problem with the temperature of sterilization has been an increase in dark current by, generally, a factor of two. However, a slight increase in the oxygen content of the photoconductor during application has decreased the dark current initially so that the increase in dark current is not a problem. There was a problem with spots on the photo surface. These spots have been observed during the initial testing of tubes and did not degrade due to sterilization. The problem was traced to faceplate cleaning procedures and faceplate imperfections. Many of the quartz faceplates have now been rejected because of microscopic imperfections. The last five or six tubes made have not had any significant spots. Phase I is now nearing completion, with the photoconductor demonstrating ability to survive the required sterilization compatibility tests.

Phase II — The shock-sensitive subassemblies have been specifically shocked at 3100 g, 0.42 millisec duration, and also vibrated. The tested subassemblies are now being life-tested at an accelerated rate. The results of the heater-cathode testing are very good. The mesh subassemblies have been also tested at 3100 g, and the results of these tests also indicate survivability to the high impact shock. The heater-cathode and the mesh were thought to be the biggest challenges in the program, and success in these areas is highly encouraging. A mechanical sample of the ceramic envelope is being fabricated, and the first tube should be completed by the first part of January. Figure 1 is a drawing showing detail of the ceramic tube. Figure 2 is the schedule of the program. Tests have also been made on the indium seal between the faceplate and the envelope, which indicates a considerable margin of safety in this area.

A parallel effort on a ceramic heater-cathode subassembly has had significant results. A ceramic heater has failed after 400 hr of operation. This is very encouraging because it was about the second or third ceramic heater tested. For future efforts, the ceramic heater will be essential if higher levels of shock are necessary.

The program is progressing well and is on schedule, and it is now approximately 45% complete.

PLANS FOR NEXT REPORTING PERIOD

Several ceramic vidicons will be fabricated and tested; the single prototype is to be delivered at the very end of the reporting period. Complete environmental testing will be done during FY 1967.

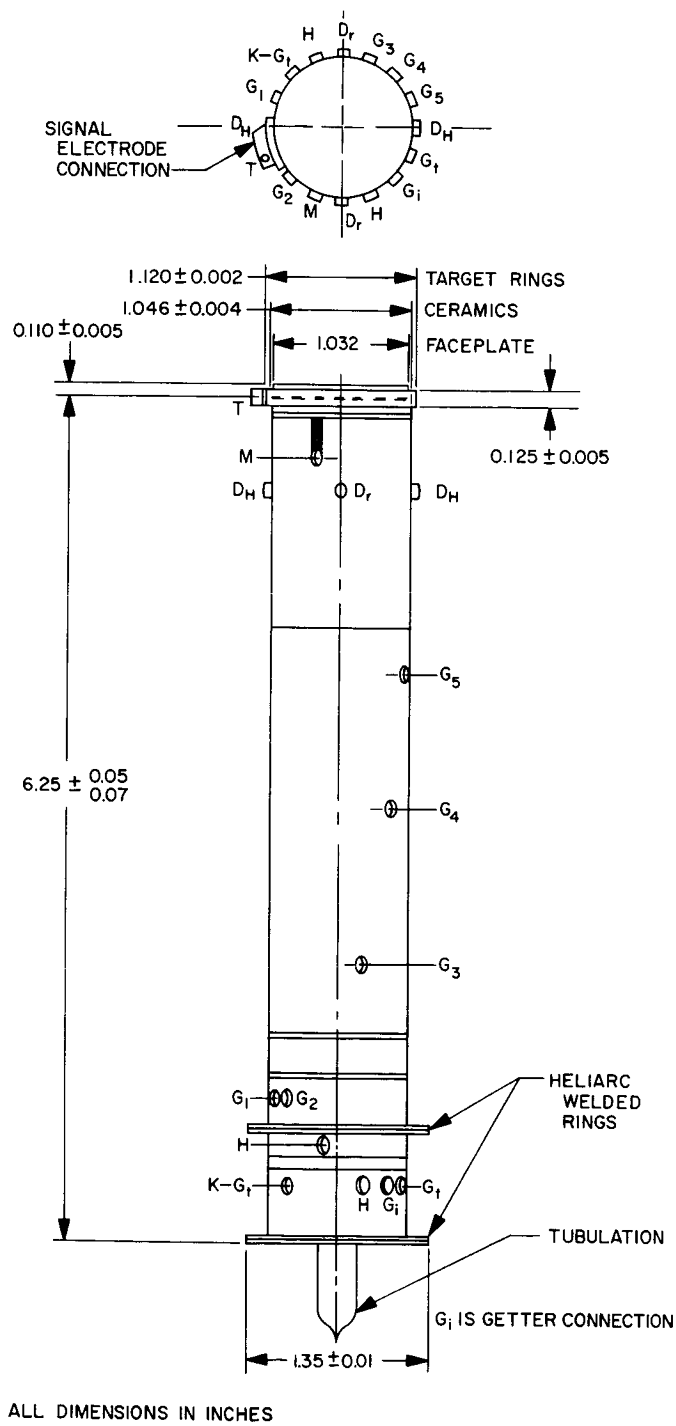


Fig. 1. Ceramic vidicon (RCA type C23053)

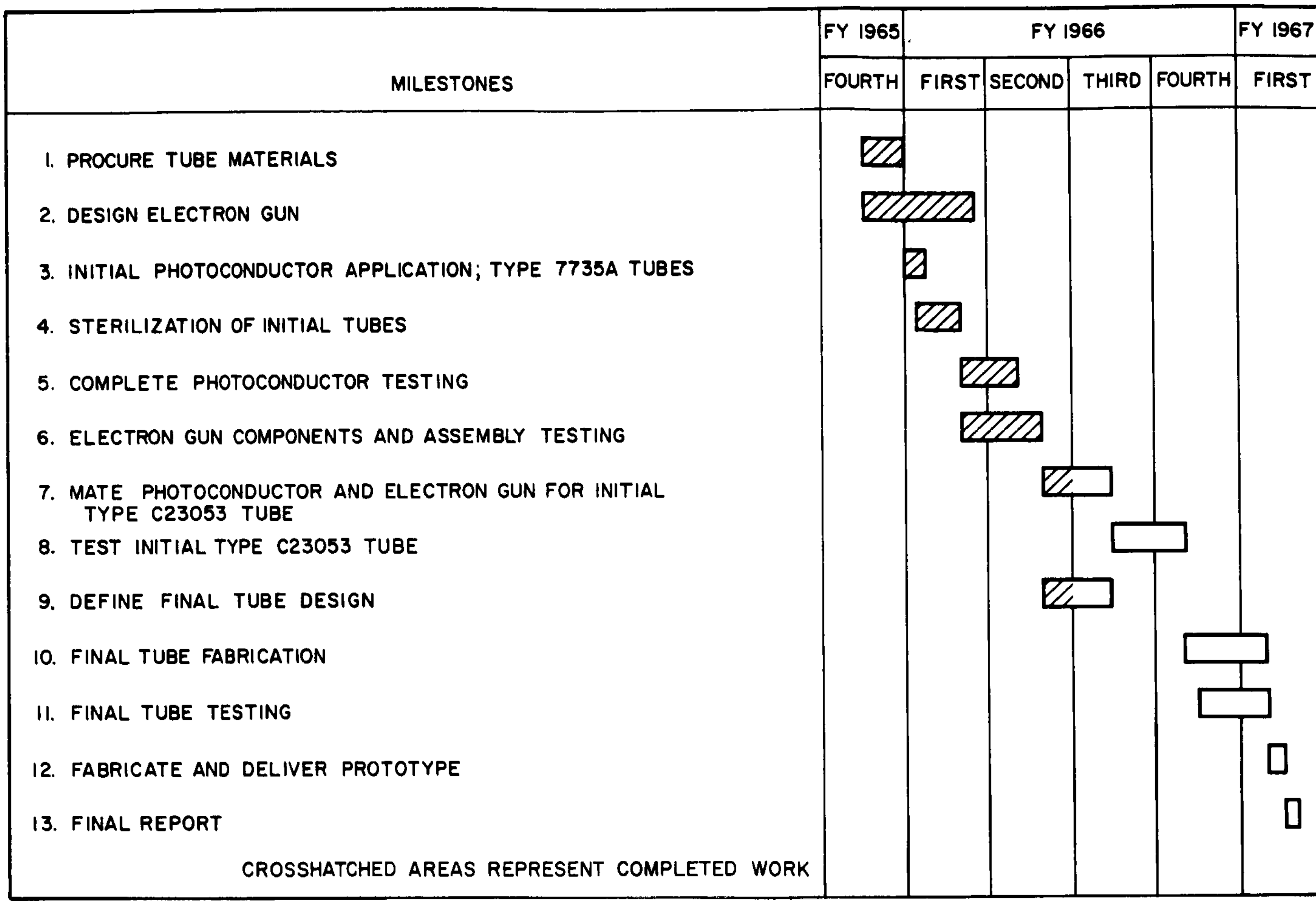


Fig. 2. Program schedule

REED-CAPACITOR MODULATOR STERILIZATION

NASA Work Unit 186-58-06-04-55
JPL 384-84401-2-3220

J. R. Locke

OBJECTIVE

The objective of this work unit is to substantiate the effectiveness of the developed production technology in overcoming problems associated with exposing the Reed-Capacitor-Modulator to repeated heat-sterilization cycles. The objective further includes assuring the existence of an organization capable of building this miniaturized modulator for future needs.

The reed-capacitor modulator has been under development since July of 1963 through a contract with the Kinelogic Corporation of Pasadena. Since August of 1964 Kinelogic's efforts have been directed toward the present task of ensuring that the reed-capacitor modulator can survive heat sterilization.

A study of this problem and refinement of the necessary technology was completed in December 1964. The main problem associated with heat sterilizing the capacitor was in minimizing the magnitude of contact potential and its thermal and temporal shifts.

To demonstrate the effectivenss of the control techniques that had been developed in the study, our contract with Kinelogic required that a reed-capacitor modulator (designated PTM 15) be built and pass the heat sterilization type approval test (XSO-30275-TST-A, dated May 24, 1963). In addition to the heat sterilization test, PTM 15 was also required to pass a 200-hr thermal cycling test. The thermal cycling test was designed to accelerate and expose any temporal shifts in contact potential that PTM 15 might have.

PTM 15 was constructed and successfully passed the heat sterilization test in February 1965, but failure of test equipment and a later vacuum leak in PTM 15 prevented the completion of required testing and the delivery of the modulator. Subsequent efforts to rebuild and test the unit were frustrated by schedule conflicts, failure of equipment, loss of key personnel, and finally indications that PTM 15 had become contaminated from the excessive rework it had experienced.

Because PTM 15 was built to demonstrate the effectiveness of the control techniques Kinelogic had developed, which were based primarily on cleaning technology and the deposition of a high purity gold, the contamination of the unit made further work on this unit meaningless. On the basis of this consideration the contract with Kinelogic was terminated October 11, 1965.

At the present a literature search has been undertaken, in conjunction with an industry sweep, to ascertain if since the inception of Kinelogic's development effort on the reed-capacitor modulator the state of the art has been advanced so as to obviate the need for continued effort on the present device.

In the event that a need for the present device still exists, preparations are presently under way to establish a vendor list of qualified organizations to build the reed-capacitor modulator based on detailed mechanical drawings and process-assembly procedures developed under the Kinelogic contract. In addition, a procurement package including a statement of work and schedule has already been prepared for requesting proposals. The decision to solicit proposals, rather than extend the contract with Kinelogic, was based on the following three considerations: (1) Since January 1965 Kinelogic no longer has the key personnel that were responsible for the research and development of the reed-capacitor modulator. (2) The bulk of the equipment Kinelogic has used on the contract was supplied by JPL. For Kinelogic to be an effective supplier, for JPL's future needs, they should have their own equipment, which they have indicated would not be profitably feasible. (3) Because of the small size of Kinelogic's organization, many of the operations associated with construction of the reed-capacitor modulator had to be subcontracted to other organizations, which had in the past caused bottlenecks and subsequent delays.

SENSOR STERILIZATION AND TEST PROGRAM
NASA Work Unit 186-58-06-06-55
JPL 384-84601-2-3220

R. A. Wengert

OBJECTIVE

The purpose of this program is to provide data and useful information which will prove the availability of the following sterilizable, ruggedized, and highly reliable components: (1) Geiger-Mueller tubes, (2) solid-state radiation detectors, (3) inorganic scintillation crystals, (4) photomultiplier tubes, and (5) optical detector-scintillation crystal assembly. To accomplish this, the development contracts are being monitored to or toward completion and the developed components are being further tested to verify the manufacturers' production capability, prove the design reliability, sterilizability, and usefulness of the items.

GEIGER-MUELLER TUBES

The contractor (EON Corporation) is investigating methods of internal surface protection in an effort to further improve the tube characteristics and enhance the reliability of the detector. Results during the second quarter were very encouraging in that if any change was experienced as a result of the heat sterilization, it was an improvement in the operating characteristics.

SOLID-STATE RADIATION DETECTOR

The contractor (Special Products Division of Technical Measurement Corporation) has completed the development contract. The final report and the detectors developed have been delivered. Analysis of the data sheets indicates only slight degradation of the operating characteristics due to the heat sterilization but a greater change when subjected to the ETO decontamination and environmental testing. After being stored in ambient conditions for several months, a further degradation has been experienced. The contractor has submitted a proposal for the improvement of the surface protection and packaging. A decision will be made early in the third quarter as to whether or not the suggestions are feasible and the effort should be continued.

INORGANIC SCINTILLATION CRYSTALS

This task is being performed by Isomet Corporation and is nearing completion. A sample package has been completed and successfully undergone the most severe of the testing requirements. Six models of the final package design have been assembled. The testing program will be completed early in the third quarter. No problems are anticipated.

PHOTOMULTIPLIER TUBES

The contractor (Electro-Mechanical Research, Inc.) has completed the tube development and testing program and is now completing the final report. Although not completely successful, the contractor has made great improvement in the tubes with a response in the visible. The investigators believe that further gains can be

made, but an evaluation of the final report will be made to determine the advisability of further effort.

OPTICAL DETECTOR-SCINTILLATION CRYSTAL ASSEMBLY

The performance of this task is being done by Isomet Corporation. The objective is to use a solid state optical detector (rather than a temperature-sensitive photocathode surface) with the scintillation crystal already shown to be sterilizable. In addition to elimination of the temperature-sensitive element, a reduction in the weight, volume, and power will be experienced. Since this task was not started until November, there is little activity to report at this time. The literature has been searched to find optical detectors which have the proper operating characteristics.

FOLLOW-ON TEST PROGRAM

The instrumentation for testing the Geiger-Mueller tubes has been received and is in operation. Difficulty has been encountered in establishing the proper discrimination level of the instrument. The manufacturer of the equipment has been made aware of the problem and will suggest a solution. The thin wall tubes developed under the basic contract have been delivered and initial testing has taken place indicating no change in the characteristics as a result of shelf life. Additional tubes will not be purchased until completion of the product improvement contract now underway.

The instruments for the console for testing the solid-state radiation detectors have been received. The system will be placed in working order early in the third quarter and testing will then be started. Twenty-four detectors, consisting of the four types developed, have been received.

STERILIZABLE CAPSULE DATA BUFFER

NASA Work Unit 186-58-06-07-55
JPL 384-84701-2-3240
R. H. Nixon

OBJECTIVE

The objective of this task is to develop a sterilizable solid-state buffer memory system. This type of memory system is required as a part of a science capsule system for advanced planetary missions.

STATUS

Four proposals were received in response to JPL's RFP 7246. The request for proposal called for a two-phase effort with phase one being a breadboard phase and phase two a flight prototype development. The system to be developed is a 20,000-bit random access NDRO memory. Stringent requirements were specified for high-reliability, low power, and sterilizability. An independent study of the sterilizable properties of the basic memory element was required.

Proposals were received from four companies:

1. RCA, Heightstown, New Jersey.

   A laminated ferrite approach was proposed.

2. Univac, Blue Bell, Pennsylvania.

   A plated wire memory element was proposed.

3. Univac, St. Paul, Minnesota.

   A planar mated-film approach was proposed.

4. Librascope, Glendale, California.

   A woven memory plane composed of plated wires was proposed.

Survey trips were made to each vendor facility in support of the proposed evaluations. Evaluation of the proposals led to a decision to support both Univac (St. Paul) and Librascope (Glendale) for the phase one effort only.

The phase one effort at Librascope will cost approximately $66,000 and will be six months in duration commencing in the third quarter of FY 1966. The phase one effort will result in a 4096-bit breadboard system and a separate study on the sterilizability of the woven plated wire memory plane. The funding for the Librascope contract will be partially supported by the Voyager project.

The proposed contract with Univac (St. Paul) is emphasizing the further development of the mated-film geometry for use as an NDRO element. The contract will primarily be a study contract and will last nine months commencing in the third

quarter of FY 1966. The total cost of the contract will be approximately $100,000. Because of the basic developmental nature of the Univac contract, it will receive primary support from the NASA Work Unit 125-23-02-14. However, since a separate study of the basic sterilizable properties of the mated-film memory element is to be conducted, the contract will receive partial support from this work unit.

At the conclusion of the two memory system contracts described in this report, the results will be evaluated and a decision will be made with regard to which approach should be allowed to continue into the phase two development of a flight prototype. It is estimated at this time that the development of a flight prototype will cost between $200,000 and $300,000 and will take approximately six to nine months to complete. Phase two should be ready for initiation in the second quarter of FY 1967.

HEAT STERILIZABLE BATTERY DEVELOPMENT

NASA Work Unit 186-58-07-01-55 (818-01-06-70*)
JPL 384-81501-2-3420

Ralph Lutwack

OBJECTIVE

The objective of this program is to develop a heat sterilizable impact resistant battery.

INTRODUCTION

JPL has a program to develop energy storage devices capable of performing satisfactorily after heat sterilization. The general objectives of the program are: (1) to obtain basic and new information regarding batteries and battery components subjected to heat sterilization procedures, (2) to develop technology to assist in the proper designing and fabrication of heat sterilizable batteries, (3) to test and evaluate components and units of heat sterilizable batteries; (4) to produce a battery which will satisfactorily meet flight program requirements. It is intended that the knowledge and technology developed in this program be such that the application can be made to a variety of modes of heat sterilization.

The requirements for the present planetary lander capsule project, that the electrical energy be delivered after heat sterilization and after sustaining the required shock and vibration loads, is so rigorous that no available battery is adequate; consequently, a complete research and development program was undertaken. The initial contract work was done by the Delco-Remy Division, General Motors Corporation, from April 1962 to June 1964. One of the conclusions derived from these contracts was that no available separator material was capable of functioning satisfactorily after sterilization at 145°C. Of the materials tested, separators fabricated from polyethylene base films by grafting with acrylic acid (Radiation Applications, Inc.) seemed to have potentialities of being modified further to yield separators with the necessary properties. On this basis, a development contract was given to RAI in September 1963, to explore this procedure. A second contract was given for a parallel effort to the Narmco Division, Whittaker Corporation, to develop separator materials from eight new thermostable polymers.

SEPARATOR DEVELOPMENT BY RAI

The RAI program, begun in September 1964, covered the fabrication and testing of 51 different materials using polyethylene as the base film. The fabrication selection of the program was as follows:

1. Three densities of polyethylene were used in each process, except when noted.

2. In each procedure the polyethylene was grafted with acrylic acid (AA) using a CO^{60} source.

*Transferred to Voyager Project in FY 1966.

3. The crosslinking procedures used were:

   a. Precrosslinking by irradiation with a 1.5-Mev electron beam to four radiation levels,

   b. Precrosslinking with three concentration levels of divinylbenzene (DVB) using a CO^{60} source,

   c. Postcrosslinking one base polymer with three concentration levels of DVB using a CO^{60} source, and

   d. Simultaneous crosslinking one base polymer with DVB and grafting with AA using a CO^{60} source.

4. The effects of molecular weight and relative humidity were explored. Each film was subjected to a test program designed to examine properties which were believed to be necessary for an adequate separator.

In the first phase of the testing program the properties of the films after heat sterilization at 137 and 145°C were determined. Samples were taken at the end of each cycle for 137 and 145°C, and measurements were made of tensile strength, acid equivalence, dimensional changes, and resistivity. The resistance measurement was the governing criterion, and in some cases repeated grafting procedures were used in efforts to lower the resistance into the acceptable range. In a few cases acceptable values were never obtained, and these materials were not tested further.

The resistance measurement for 42 materials of the 51 prepared was low enough to allow complete testing in which the final test phase was for electrical capacity retention after three sterilization cycles at 145°C. The retention was greater than the arbitrary acceptance level of 90% after five deep cycles of charge and discharge for seven materials, the best capacity retention data being obtained for: (1) a material fabricated by precrosslinking 0.917 density polyethylene with divinylbenzene and then grafting with acrylic acid and (2) a material fabricated from precrosslinking 0.917 density polyethylene with the electron beam source to a total radiation dose of 70 Mrads and then grafting with acrylic acid. RAI has delivered 500 ft^2 of each of the two best materials; these are being evaluated further by ESB and JPL.

The conclusions derived from the RAI contract are:

1. No differences of separator degradation at 137 and 145°C were detected.

2. No differences of separator properties were detected for the conditions of sterilization in the absence of, and in the presence of, the Ag electrode.

3. No further changes in properties occurred after the first cycle at either 137 or 145°C.

4. The seven separator materials from which the cells having greater than 90% capacity retention were constructed were all made from 0.917 density polyethylene.

5. Satisfactory materials can be prepared using either irradiation or divinylbenzene crosslinking procedures.

SEPARATOR DEVELOPMENT BY NARMCO

In the contract to the Narmco Division, Whittaker Corporation, begun in June 1965, the field of the new thermostable polymers is to be investigated as a source for separator materials. In phase I of this program, Narmco is to: (1) synthesize eight distinct thermostable polymers to the highest possible molecular weight and/or to varying degrees of condensation or modification, (2) test the synthesized polymeric compounds, (3) fabricate films from the promising polymeric compounds, and (4) test the films for resistance to sterilization at 137 and 145°C. In phase 2, a 500 ft^2 quantity of one candidate is to be produced and fully tested as a battery separator.

The polymers to be synthesized comprise polymeric aliphatic analogs of benzimidazole, benzoxazole, benzothiazole, and two quinoxalines. The aliphatic moieties derive from glutaric and sebacic acids by condensation with 3, 3'-diaminobenzidine, 3, 3'-dimercaptobenzidine, and 3, 3'-dihydroxybenzidine. The quinoxalines are prepared from 4, 4'-diphenyl ether bis glyoxal and 3, 3'-diaminobenzidine and 3, 3', 4, 4'-tetraaminodiphenyl ether.

As a prerequisite to the film preparation stage each of the synthesized polymeric compounds is subjected to preliminary screening tests to determine whether it has the necessary chemical properties for temperature and KOH resistance. These tests are:

1. General analysis using infrared and ultraviolet spectrophotometric methods.

2. Determination of hydrolytic stability at 145°C in aqueous 40% KOH using inherent viscosity methods.

3. Determination of oxidative stability in air at 250°C using the method of isothermal weight loss.

4. Determination of oxidative stability in aqueous 40% KOH solutions containing silver ion.

5. Solubility tests in appropriate solvents.

6. Determination of the glass transition temperature.

On the basis of the results of these preliminary tests, promising polymeric materials are selected for further study and evaluation.

Polymeric materials, which possess the required temperatures and KOH resistances, are then evaluated in the film formation phase at which point the

processibilities of the polymers as films are studied and properties of the resultant films are measured. The film formation phase includes studies of solution casting and hot-melt techniques and studies of the curing of films prepared from prepolymers. Measurements of hydrolytic and oxidative stabilities are made to determine the resistance to heat sterilization. These are prerequisites to the full test program of measurements of electrical resistivity, electrolyte solution absorption, and rate of diffusion of Ag ion.

Although each of the polymers which has been synthesized has the requisite chemical resistance properties, the effort has now concentrated on the development of films from poly 2, 2' (octamethylene) 5, 5' -bibenzimidazole. This emphasis is due to the superior film processibility characteristic of this polymer. The work is now being directed to attempting chemical and physical modifications in efforts to lower the initial high resistivity value of 1.6×10^6 ohm-cm. A procedure in which Li Cl was incorporated into the film and then leached out, yielding a microporous structure, has been explored. However, the resistivity value was lowered only to 2.0×10^5 ohm-cm by this process. Currently, chemical procedures are being used in which hydroxyethyl or carboxyl groups are introduced into the polymer via substitution at the -NH site in the imidazole ring and by sulfonation. These procedures are intended to introduce increased hydrophyllic character into the polymer, resulting in decreases in resistivity.

RESEARCH AND DEVELOPMENT PROGRAM FOR THE Ag-Zn BATTERY BY ESB

A research and development contract was awarded to the Electric Storage Battery Co. in September 1965 to study, develop, fabricate, and test sealed Ag-Zn and Ag-Cd battery cells capable of functioning satisfactorily following heat sterilization, high impact, and vibration procedures. The contract provides for electrochemical studies on electrodes, electrolyte solutions, and separators; for chemical and physical studies of case materials; and for the design, fabrication, and testing of cells of both the Ag-Zn and Ag-Cd systems. The testing of the most promising plastics for cells, polyphenylene oxide (General Electric) and polyphenylsulfone (Union Carbide), has begun. Preliminary cell designs are being considered, and calculations of stresses associated with certain cell designs have been made. This contract and the in-house program at JPL are the major comprehensive efforts underway at this time in the JPL sterilizable battery program.

Ni-Cd TESTING PROGRAM AT TRW-STL

Ni-Cd cells (Sonotone, D size, 3.5 amp hr) are being tested and evaluated in a program by TRW Space Technology Laboratories under contract to JPL. The program comprises testing the float, stand, and cycle characteristics of sterilized cells which are uncharged, charged partially to various degrees, and fully charged. Preliminary results show that the loss of capacity increases with increasing degrees of charge. The data are not sufficient to indicate the effects on cycling. The tests are continuing.

IN-HOUSE PROGRAM AT JPL

The in-house sterilizable battery program at JPL has been intended to be an advanced development effort and to serve as a complementary effort to contractual work. This program comprises cell testing and evaluation, resistivity

measurements, case material testing and evaluation, and impact testing. This pattern will continue with increasing emphasis on developing a particular battery to meet specific space flight requirements.

STERILIZABLE SOLID ROCKET DEVELOPMENT

NASA Work Unit 186-58-08-01-55
JPL 384-81901-2-3810

W. Dowler
F. Anderson
C. Robillard
J. Shafer

OBJECTIVE

The long-range objective of this task is to understand and solve the engineering problems involved in supplying solid propellant rocket motors for those planetary exploration spacecraft that will have to be sterilized to assure planetary quarantine.

Screening tests, during a previous report period, on propellants developed and supplied by industry, indicated that at least two offered some promise of withstanding, as a small free-standing propellant specimen, three 36-hr cycles at 295°F. These were (1) a relatively hard propellant based on an ammonium perchlorate-polyester-styrene copolymer, AN583AF, which was most applicable if the charge was to be a cartridge design and (2) an elastomeric propellant based on ammonium perchlorate - PBAA-MAPO propellant, TP-H3105, which was more applicable for case bonded motors.

At this point then, a two-pronged approach to solving the engineering problems has been adopted:

1. To see whether the most promising existing formulation is capable of accommodating to the severe mechanical stresses when used in a heat-sterilizable motor design, i.e., to demonstrate motor feasibility even though motor performance may have to be degraded significantly through design conservatism.

2. To conduct experiments to provide an improved propellant and better motor designs and to understand better the design criteria of heat sterilizable motors and the requirements for motors which are scaled up in size.

The Voyager Project Office is also funding a task on studies and development of heat-sterilizable motors, work which supplements the efforts of this task. Approximately 25% of the work of objective (1) above and 75% of the work toward objective (2) is performed under this task and the balance of the effort under the Project Office task.

An abstract covering the current heat sterilization work has been submitted for presentation at the forthcoming summer meeting of the ICRPG.

FEASIBILITY OF HEAT STERILIZABLE MOTORS (by J. I. Shafer)

Major emphasis is oriented toward the preparation of a small flight weight motor as quickly as possible in order to have assurance that the real motor problems are recognized and being worked on. Because hardware for a 12-in. diameter, 60-lb

Syncom flight motor (See Fig. 1) is available, and is a convenient size, it will be used.

Of the two classes of propellants, PBAA-MAPO and polyester-styrene, that seem promising for sterilizable systems, the former appears to have higher overall motor performance potential; therefore, greater emphasis is being placed on it. Several PBAA-MAPO formulations, which were originated at this Laboratory and are free of industrial proprietary constraints, have been prepared to evaluate their mechanical properties and ability to withstand heat sterilization. The choice of a particular propellant formulation for motor work will be made in late January or early February. Figure 2 shows one formulation in the form of a 3-in.-square block 6 in. long which failed internally after four 36-hr cycles at 295°F; this matches the results from previous PBAA-MAPO system tests.

A Syncom motor using that propellant, but no other material or design revisions, has been cast and is now curing. When this reference motor is put through sterilization cycles during February, it should reveal whether conventional cast in-case bonded charge designs may prove to be feasible or whether expansion joints, boots, special liners, or other expedient design devices are necessary.

Because of the importance of charge design and stress analysis to this task,a study contract was let to Thiokol Elkton to determine those design features which are most desirable in heat-sterilizable motors. The study should be completed about the middle of January.

Facilities, in the form of an oven capable of sterilizing motors up to 36 in. in diameter by 36 in. long, have been constructed at the Edwards Test Station and check-out tests are currently under way.

Because of the potential hazard associated with heat sterilizing progressively larger motors, (i.e., the thermal degradation or "cook-off" problem) plans are under way to let a contract to Naval Ordnance Test Station personnel, who are currently conducting studies of this type. An attempt will be made to check their model and their ability to predict the relationship of time-to-deflagration vs temperature for a Syncom motor from tests on smaller specimens. It is hoped that results will be available by April or May of next year.

The Voyager Project Office has been reviewing its particular requirements for sterilized systems. This effort will be followed and if changes are adopted, they will be taken into consideration in forthcoming work.

STERILIZABLE PROPELLANT DEVELOPMENT (by F. A. Anderson and C. Robillard)

Because existing solid propellants have only a very limited margin in their ability to withstand heat sterilization, it seemed warranted to develop an improved propellant for this type of application. Charges subjected to sterilization heat cycles at 295°F in unsealed bulk samples have become deformed and have eventually cracked after 4 to 5 cycles. The deformation takes the form of distentions or bulges (see (Fig. 2), which suggest that failure is caused by expansion of gas or volatiles trapped

in the charge. It is not known whether the volatiles were produced during the heat cycle or whether they existed as impurities in the cured propellant.

These samples were heat-cycled with surfaces exposed to the atmosphere, resulting in crust formation. Heat sterilization of the ultimate deflection motor will be conducted with the motor sealed from the atmosphere. (At the present time, there are no plans to provide the motor cavity with an inert atmosphere.) Therefore, future heat cycling tests will be conducted with charges sealed from the atmosphere.

To date, no attempt has been made to purify propellant ingredients; therefore, some work is needed to determine whether or not charge failure can be prevented by prior removal of volatile impurities from propellant ingredients.

The primary objective is to obtain a propellant which (1) has adequate physical properties after cure, (2) survives 6 heat cycles in bulk without deformation, and (3) exhibits as little change as possible in physical properties after cycling.

The work to date, as a result of a very cursory initial screening of potential binder systems, has concentrated on the development of an ammonium perchlorate/carboxyl terminated polybutadiene binder system. Several different multifunctional imine and epoxy curing agents have been investigated. The effects of varying the crosslinking ratio have also been studied. To date the most promising results have been obtained with an imine-cured system. A formulation has been developed which withstood three 36-hr cycles at 295°F and maintained dimensional integrity as well as reasonbly good physical properties. Work is continuing with this basic system in an effort to improve the physical properties as well as its heat sterilizability.

Future work will consist of the following:

1. Determination of the volatiles given off by the propellants and by the propellant ingredients.

2. A comparison of the reference PBAA system with carboxy terminated polybutadiene from two different sources using MAPO as the imine crosslinking agent.

3. Determination of the effect of ingredient purification on propellant thermal stability.

4. Determination of the effect of heat cycle environment on propellant thermal stability.

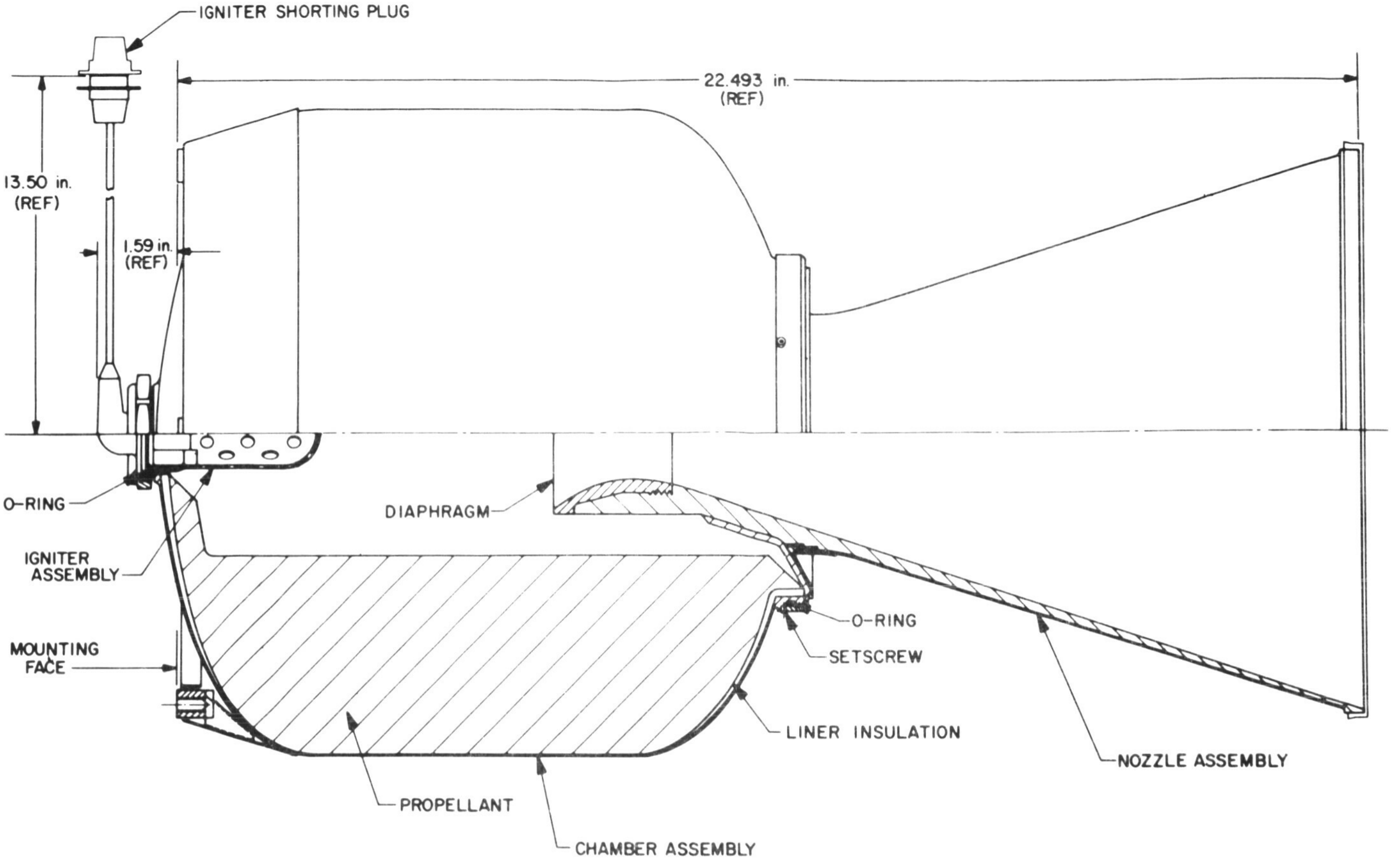


Fig. 1. Cross-sectional drawing of flight weight SYNCOM motor

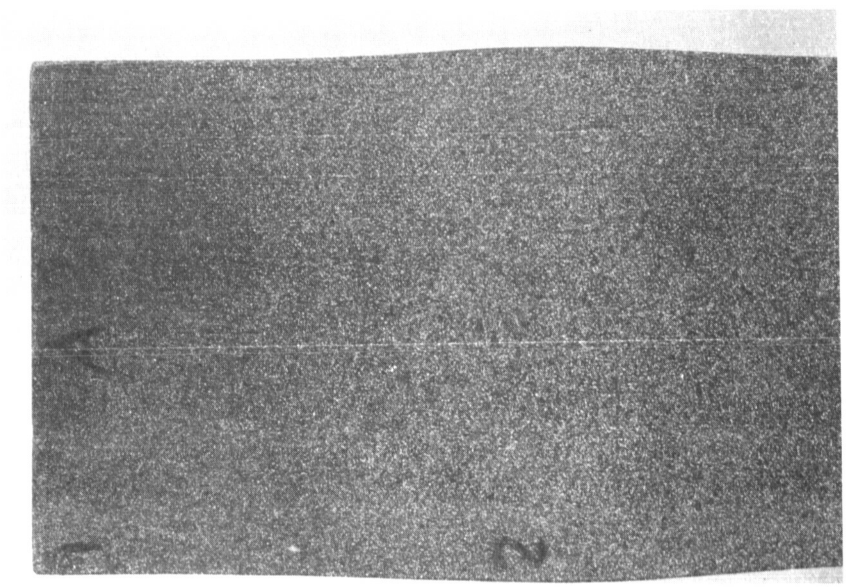


Fig. 2. Propellant block after four
36-hr cycles at 295°F

STERILIZABLE PROPULSION SYSTEM DEVELOPMENT

NASA Work Unit 186-58-08-02-55
JPL 384-82101-1-3840
D. D. Evans

OBJECTIVE

The objective of this work unit is to develop the technology required for a sealed, heat-sterilizable liquid propellant supply system. Such systems will be an integral part of propulsion systems for probes and/or landing vehicles which enter planetary atmospheres.

STATUS OF CONTRACT

This work will be handled primarily by an industry contractor. This work unit was not formally approved until December 7, 1965, therefore limited progress was made. However, a work statement for the contract has been finalized and specifications published. The work statement provides for (1) the design of a modular liquid propulsion system at the 100-lbf thrust level, (2) individual component development and test, (3) a propellants and materials compatibility test program, and (4) assembly, heat cycling, and demonstration firings of the complete propulsion system. Contractor selection is expected to be completed by the end of the third quarter of FY 1966.

STERILIZABLE PYROTECHNICS DEVELOPMENT PROGRAM

NASA Work Unit 186-58-12-01-55
JPL 384-82301-2-3810

A. G. Benedict

OBJECTIVE

The objective of this program is to ensure that technologies are available to allow design, fabrication, and test of any reliable explosively actuated device which might reasonably be needed for a spacecraft application and which may be required to withstand thermal sterilization.

It has already been determined that a fairly comprehensive range of thermally sterilizable explosive materials is available, percussion primer mixes being the only significant area questionable in June 1965.

The effect of thermal sterilization in explosively actuated devices relates mainly to the increase in temperature range which must be withstood by materials having different temperature coefficients of expansion, a problem which becomes serious in electrically initiated cartridges (squib initiators) if the use of magnetic materials must be avoided.

STERILIZABLE SQUIB INITIATOR

A contract let in February 1965 to the Hercules Powder Company for completion in September of a development of a small ceramic four-pin sterilizable nonmagnetic squib header was terminated on the due date in the light of unsatisfactory progress. A "backup" contract was negotiated as a matter of urgency with Space Ordnance Systems, Inc., and this company completed the necessary development within the month of September.

The work done by Hercules and by Space Ordnance Systems, supported by in-house work at JPL, indicates that:

1. The 300 series of stainless steels are impractical for small high-pressure squib bodies for nonventing applications, as thread yield allows leakage at body seals.

2. Inconel 718 is the best choice of body materials for nonmagnetic applications.

3. Headed pins resting on pressure-pads provide positive pin-to-ceramic seals, and should be used for high-reliability seal applications until proven advances are made in the state of the art of ceramic-to-metal brazing techniques.

A contract for development of a small mating connector was let to Nu-Line Industries in August; their work is substantially complete and prototype connectors have been delivered. Preliminary evaluation indicates that the prototype connectors represent a marked improvement over the Mil-C-26482 series for certain spacecraft applications, but that a redesign of drawing tolerances is desirable; this work is being done by JPL. The new connector provides for the same pin diameters and

spacing as the MIL-C-26482 series, and additionally provides for continuity of shielding and for grounding before contact, all within a comparatively small envelope. Figure 1 compares the two connectors as mated to the sterilizable squib.

Response to an RFP for development of an anti-static-discharge shunt was disappointing, so an attempt will be made to do initial development at JPL. Preliminary tests of silicon carbide power in an epoxy matrix gave unexpectedly encouraging results; it is expected that evaluation of this approach will be complete by June 1966.

Deposited-film bridges developed at JPL successfully withstood severe temperature shock and exhibited no-fire capabilities about six times greater than comparable wire bridges. Proposals for development of manufacturing procedures have been received and evaluated, and it is expected that a contract will be negotiated for completion by August 1966.

PERCUSSION INITIATION

Staff shortages delayed progress on tests of the high-temperature primers G-11 and G-16, but tests being done by Remington Arms under contract to Frankford Arsenal have demonstrated that the primers do not degrade significantly under exposure to 300°F for several hundred hours. These results coupled with preliminary tests at JPL indicate that earlier anomolous behaviour of these primers is almost certainly attributable to sensitivity of the primers to handling during assembly into cartridges; it is proposed now to conduct only a limited test program to examine this and to establish approximate limits to the tolerable abuse.

TEST EQUIPMENT

Although a time-domain reflectometer, a 40-kv vacuum-capacitor static discharge assembly, and an 80,000-psi static pressure test assembly have been purchased or assembled, staff shortages have delayed development of test techniques to take full advantage of this equipment.

Equipment for measuring the thermal time constants of squibs by the "third-harmonic" technique developed by Prof. L. Rosenthal (N. O. L. White Oak) has been assembled and put into service; the value of the thermal time constant as an inspectable parameter has become so evident that efforts are being made to improve on the present equipment.

SUPPORTING TECHNOLOGIES

Dr. B. Jamieson (now of Stanford) was employed (in the summer of 1965) as a consultant to evaluate small-sample tests by attributes, particularly the "Langlie" method. His report was pessimistic about the value of such tests when extreme percentiles were of importance, and a ramp no-fire test (by variables) evolved at JPL consequently appears to offer marked improvement over the Bruceton-type test more conventionally used with squibs.

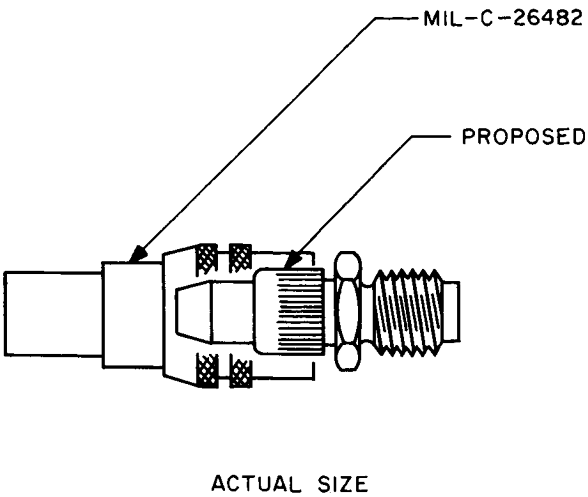


Fig. 1. Comparison of squib using MIL-C-26482 and proposed connectors

ESTABLISH AN APPROVED LIST OF HEAT STERILIZABLE ELECTRONIC COMPONENT PARTS

NASA Work Unit 186-58-13-01-55 (818-01-06-70*)
JPL 384-80101-1-1520

J. Visser

OBJECTIVE

To support the NASA thermal sterilization policy by studying the effects of the thermal sterilization environment on the reliability of electronic piece parts during long life. The study will result in the establishment of a list of electronic piece parts capable of operating reliably for a minimum of 10,000 hr after being subjected to heat sterilization.

PROGRESS OF INDIVIDUAL TEST PROGRAMS (see Fig. 1)

1. ZPP-2101, Capacitor Test. The original 10,000-hr test program has been completed. Certain critical capacitor types will be continued on life test until 16,000 hr have elapsed. The final 10,000-hr test report has been released. In general, there is a severe problem with certain capacitor types such as solid tantalums. Consequently, a capacitor retest has been initiated (see No. 13 below).

2. ZPP-2102, Fixed Resistor Test. The original 10,000-hr test program has been completed, and the final report is scheduled for release by January 29, 1966. Certain critical resistor types will be continued on life test until 16,000 hr have elapsed. With the exception of 1/10-w carbon composition types, the resistors tested are compatible with heat sterilization requirements.

3. ZPP-2103, Variable Resistor Test. The 10,000-hr life test has been completed, and the test agency is preparing their final report. The JPL final report is scheduled for release by February 25, 1966.

4. ZPP-2104, General Diode Test. The test agency is preparing the test fixtures and equipment. Initial measurements should be completed by January 28, 1966.

5. ZPP-2105, Varactor Diode Test. The 10,250-hr measurements are in progress. From the information obtained to date, the varactor diodes being tested are compatible with the heat sterilization requirements.

6. ZPP-2017, Fuse Test. All of the fuses have been delivered to the test agency, and the test agency is completing fabrication of the test fixtures and equipment, Initial measurements should be completed by January 19, 1966.

*Transferred to Voyager Project in FY 1966.

7. ZPP-2110, Thermistor Test. All of the thermistors have been delivered to the test agency, and the test agency is in the process of fabricating the test fixtures and equipment. Initial measurements should be completed by January 31, 1965.

8. ZPP-2113, Transistor Test. The 2,000-hr life test measurements are in progress. A 2,000-hr interim report is scheduled for release by March 25, 1966. Twelve additional transistor types will be added to the test.

9. ZPP-2116, Crystal Test. Philco WDL was selected to perform the test program. The test is scheduled to start February 15, 1966.

10. ZPP-2119, Relay Test. Sperry Utah Company was selected to perform the test program. The test is scheduled to start February 16, 1966.

11. ZPP-2121, Digital Microcircuit Test. A total of 3,950 hr of life testing have been completed. The 2,000-hr interim report is scheduled for release February 25, 1966. All of the data has not been analyzed at this time. Consequently, no conclusions have been formulated.

12. ZPP-2124, Inductor Test. Philco WDL was awarded the contract. The test equipment and fixtures are being prepared. Initial measurements are in progress.

13. ZPP-2108, Capacitor Retest. Preston Scientific, Inc. was awarded the contract. The parts are on order and the test should start by February 15, 1966.

14. ZPP-2126, Temperature Gradient Test. This test is intended to determine the time-temperature relation between the interior and exterior of component parts when exposed to heat sterilization. The final measurements are in progress. The final report is scheduled for release February 15, 1966.

15. ZPP-2118, Ethylene Oxide Test. The Boeing Company, TRW, and Hughes Aircraft were selected to perform a study phase of the effects of Ethylene Oxide on component parts. One of the three companies will be selected to perform a test program to verify the conclusions of the study phase.

16. ZPP-2122, Linear Microcircuits. The parts have been mounted and initial measurements are in progress.

17. ZPP-2117, Part Packaging Program. The program has been cancelled because the funds were withdrawn.

COMP. FAMILY	SPEC. ZZP-	SPEC. IN PREP.	SPEC. COMPLETED	CONTS. NEGO. AND APPROVAL	CONTS. AWARDED	VISUAL INSP.	INITIAL MEAS.	STERIL. TEMP. CYC. AND MEAS.	ENVIRON. TEST AND MEAS.	START LIFE TEST	100-hr MEAS.	250-hr MEAS.	500-hr MEAS.	1000-hr MEAS.	2000-hr MEAS.	6000-hr MEAS.	8000-hr MEAS.	10,000-hr MEAS.	250-hr FOLLOWON MEAS.	FINAL REPORT	CONTRACT CLOSED OUT	COMPLETED HOURS OF LIFE TESTING
CAPACITORS	2101-GEN																			▽		*13,350
FIXED RESISTORS	2102-GEN																			△		10,250
TRIMMING RESISTORS	2103-GEN																			△		10,250
VARACTOR DIODES	2105-GEN																		△			10,250
GENERAL DIODES	2104-GEN						△															
TRANSISTORS	2113-GEN														△							2,000
MICROCIRCUITS DIGITAL	2121-GEN														▽							3,940
FUSES	2107-GEN						△															
CRYSTALS	2116-GEN			△																		
RELAYS	2119-GEN				▽																	
MAGNETICS	2124-GEN						△															
THERMISTORS	2110-GEN					△																
CAPACITOR RETEST	2108-GEN				▽																	
TEMPERATURE GRADIENTS	2126-GEN				▽	NA																NA
PART PACKAGING	2117-GEN				CANCELLED																	
ETHYLENE OXIDE	2118-GEN			△		NA																NA
MICROCIRCUIT LINEAR	2122-GEN						△															
SCREENING PROGRAM	2125-GEN	△				NA																NA

△ = IN PROGRESS

▽ = COMPLETED

* = FOLLOW-ON LIFE TEST OF CRITICAL TYPES

NA = NOT APPLICABLE

Fig. 1. Test status summary sheet as of December 31, 1965

STERILIZABLE POLYMERS
NASA Work Unit 186-58-13-02-55
JPL 384-83801-2-3510

Donald P. Kohorst

OBJECTIVE

The purpose of this program is to determine the effects of ethylene oxide-decontamination and thermal sterilization on spacecraft polymeric products. The program plan is to subject products to a type approval ethylene oxide environment,[1] a TA thermal environment,[2] and a combination of both. Each product is evaluated by standard tests before and after each exposure. The results are compared for signs of incompatibility. Products that are considered incompatible after thermal exposure are dropped from further evaluation. Test data obtained are carefully evaluated and each product is rated for its compatibility with respect to decontamination and sterilization. These ratings are then used for making selections of polymers for each spacecraft application.

PROGRAM STATUS

The work is being carried out as two tasks, the first, evaluation of thermal effects is being done by the JPL Polymer Research Section and the second, evaluation of ethylene oxide and combined ethylene oxide and thermal effects is being done by the Hughes Aircraft Company under contract.[3] Both tasks were started in October 1964.

In the JPL work 166 products are in the test program. All of these have been exposed and tested. At this time the data are being compiled and evaluated prior to rating each product for compatibility. Results and status have been reported in JPL internal documents. Complete results on this segment of the work will be reported by JPL Technical Report in the first quarter of 1966.

In the Hughes task, 69 products are under test. They were taken from the 166 products stated above. At the present time, 57 have been exposed and evaluated for ethylene oxide effects, and 30 have been exposed and evaluated for the combined exposure. Results to date have been reported in Hughes Aircraft Co. monthly reports[3] 1 through 14 and by a semiannual report No. P65-57, covering October 1, 1964, to April 30, 1965. Work on the remaining products is progressing smoothly. Planned completion date is March 31, 1966.

RESULTS AND DISCUSSION

In general the results obtained to date are very encouraging. Only a very few of the products tested show extensive degradation. Even these are not completely unserviceable. Most products exhibit a small change in properties but not a serious

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[1] A mixture of 88% Freon and 12% ethylene oxide as described by JPL Spec. XSO-30275-TsT-A.

[2] Three 36-hr cycles at 145°C as described by JPL Spec. GMO-50198-ETS.

[3] JPL Contract No. 951003

loss. Many of the adhesives tested actually have improved shear strength. It appears that ethylene oxide exposure is in general much less damaging to polymers than heat exposure.

Surprisingly a large number of the polymers show a volume change after exposure. This is an important property to many applications as it is a cause of unwanted tensile or compressive stress in a component. Ethylene oxide usually causes a volume increase while heat causes a volume decrease. With respect to ethylene oxide a volume increase is believed to be caused by physical absorption of the gas – swelling the polymer. Heat on the other hand probably causes a volume decrease because of volatilization of some ingredients as it is usually accompanied by a weight loss.

Of significant interest are two excellent high-temperature films, H-film and Tedlar which lose significant strength after exposure to ethylene oxide. This was not expected because of their unusually high stability. Physical absorption is believed responsible for this effect, but chemical reaction is also being investigated.

To simplify using the data, a rating system is being devised that will separate tested products into three categories, compatible, marginal, and incompatible. Use of products rated compatible will be required unless unusual circumstances require use of a marginal or incompatible product. However, devising a criteria for rating has presented problems. Because so little is known about the minimum properties required for each application, it is difficult to set the limits for each rating category without being somewhat arbitrary.

This program is aimed at evaluating polymers for the effects of decontamination and sterilization only. It must be understood that many other factors such as vacuum stability and radiation resistance must be evaluated before a material is qualified for spacecraft use.

FUTURE PLANS

A major alteration in the program is being planned because of a change in the Specification for the type approval decontamination and sterilization environments. Because the new exposure times, temperatures and number of cycles are substantially different from the ones previously used it becomes necessary to re-evaluate a large percentage of the products already tested. In addition, products for applications not covered in the initial program and new products will also be evaluated. It is estimated that about 200 products will be tested to the new type approval levels. In general the program plan to be followed will be the same as before.

STERILIZABLE ELECTRONIC EQUIPMENT PROCESSES

NASA Work Unit 186-58-13-03-55
JPL 384-85301-2-3570
R. F. Holtze

OBJECTIVE

The primary objective of this work unit is to develop and qualify sterilizable materials applications and processes for assembling and packaging of electronic equipment. This task will develop the required instrumentation for testing the process applications to evaluate presently used materials and process methods for sterilization effects, and then to test new materials and methods in the deficient areas until an adequate set of sterilizable electronic assembly processes is obtained.

Supporting objectives include the following:

1. Measurement of pressures generated by various resin systems as a function of temperature and the development of a method of encapsulation which reduces these pressures to a safe limit.

2. The development of a subminiature pressure transducer which can be embedded permanently in a test module to monitor the pressure generated by the embedment material on the electronic components over an extended range of -120°F to +300°F.

ELECTRONIC EQUIPMENT PROCESSES

General

Contract 951214 was issued June 1, 1965 to Northrop Space Laboratories and funded with FY 1964 funds. This work covers investigations into four areas of interest: (1) embedment of welded modules, (2) conformal coating of printed wiring board assemblies, (3) adhesive bonding as required in electronic equipment, and (4) component lead strain relief for component mounting. As part of this work, a modification was issued November 3, 1965 to the contract providing for more complex modules with a higher level of instrumentation and control designed to determine any sterilization effects occurring due to interactions between the material and components of the module. This modification used FY 1965 funds and increased the contract to $53,000.

Test Plans

Test plans covering the four tasks were submitted by Northrop Space Laboratories and have been approved. A general outline of the procedures is as follows.

Subtask 1 (Embedment of Welded Modules)

This plan covers a series of modules embedded in an epoxy base, syntactic foam material. Each module contains 18 components with leads welded to pins of a wirecon header and/or to interconnect ribbons. Five carbon resistors are included as components within the module, and they are used to determine the module's internal stresses on embedded components. These resistors have been calibrated so as to

determine changes in resistance versus external pressure. The remainder of the components are used to determine any degradation in operating parameters as a result of either the embedment or sterilization treatments.

Subtask 2 (Conformal Coating of Printed Wiring Board Assemblies)

This plan covers a number of board assemblies each containing 18 components mounted between pairs of bifurcated terminals. Assemblies with and without conformal coating are subjected to the sterilization treatments. Four of the mounted resistors are used as pressure indicating devices as in Subtask 1 and the remainder of the components are tested for any degradation in operating parameters as a result of either the conformal coating or the sterilization processes.

Subtask 3 (Adhesive Bonding of Metal and Plastic Surfaces)

This plan consists of a series of one inch wide, epoxy glass, laminate strips bonded to surface treated magnesium alloy. Lap shear tests of the bonded specimens are conducted to determine sterilization effects.

Subtask 4 (Strain Relief of Component Leads)

Test specimens are the same configuration as those for Subtask 2. Strain gages mounted on the component leads measure the dimensional change (strain) caused by the soldering process, and then measure any additional strain due to the subsequent sterilization treatment. Operating parameter measurements are also taken on the various components to determine the effects of these strains on solder joints or part performance. These results will determine whether the method of mounting components with straight leads between pairs of terminals is acceptable or if methods of lead strain relief should be developed, tested, and employed.

Present Status

All components have been burned in, screened, and operating parameters established. Fabrication of modules is under way and will be completed by January 10, 1966. No serious problems have been encountered to date.

Future Plans

It is estimated that all modules will have been completed by January 10, 1966. At that time, they will be exposed to the sterilization cycles and effects determined. No definite decision has been obtained as to the sterilization cycles to be used.

All test results will be analyzed and a decision made as to the effectivity of the instrumentation techniques used and the suitability of the process materials tested for use in sterilizable modules. It is expected that additional materials will be qualified for each principal equipment process because of different requirements of various types of electronic equipment. These materials for evaluation will be selected from those that have passed the tests conducted by the Materials Section under Work Unit 186-58-13-02, Sterilizable Polymers.

INVESTIGATION OF EMBEDMENT STRESSES IN EMBEDDED MODULES

Stress Measurements Using Pressure Calibrated Mercurial Thermometers

The embedment pressure, which is a function of the difference of thermal expansion coefficients of the embedment materials and the electronic components, normally increases as the temperature decreases. A technique described in the literature using pressure calibrated mercury thermometers to measure embedment pressures provided an immediate solution to the problem. An additional advantage is that a thermometer bulb is a reasonable approximation in size and shape to many electronic components used in encapsulated modules. Disadvantages, of course, are the lower temperature limit of -40 °F where mercury freezes, and the temperature range of the thermometer itself.

A hydrostatic calibration fixture using a dead weight tester was built as shown in Fig. 1 to pressure calibrate mercury thermometers to 7600 psi. The oil temperature next to the thermometer bulb was measured by a thermocouple to provide a temperature correction, giving a calibration accuracy of ±0.1 °F. This would correspond to an approximate ±10 psi pressure change. After calibration, the thermometer bulb, together with an adjacent thermocouple, was installed in a mold, prior to casting of the resin system. After curing, the sample with the embedded thermometer and thermocouple was exposed to the required temperature range. The difference between the thermocouple temperature reading and the thermometer reading is the pressure exerted by the resin system on the bulb.

Development of a Low Stress Encapsulation System

Based on the measuring technique above, the pressures exerted by various types of encapsulation systems were determined as a function of temperature. The pressure-vs-temperature curve for a clear rigid system, a semirigid material with microballoons, and the same semirigid material over a compressible freeze coat are compared in Fig. 2. Measurements at the low-temperature end were limited to -40 °F. The upper temperature limit is dictated by the cure temperature or the temperature to which the embedment material will be subjected.

In an attempt to extend the range of pressure measurement to the desired -120°F to +300°F, some pressure sensitive components such as carbon composition resistors have been calibrated up to 10,000 psi. Temperature effects on the same components have also been run. Further work has been suspended due to lack of technician personnel.

Future Plans

Development of an extended temperature range pressure transducer will resume when technician personnel become available.

Pending completion of a few tests, a final report will be prepared on the mercurial thermometer technique of pressure measurement.

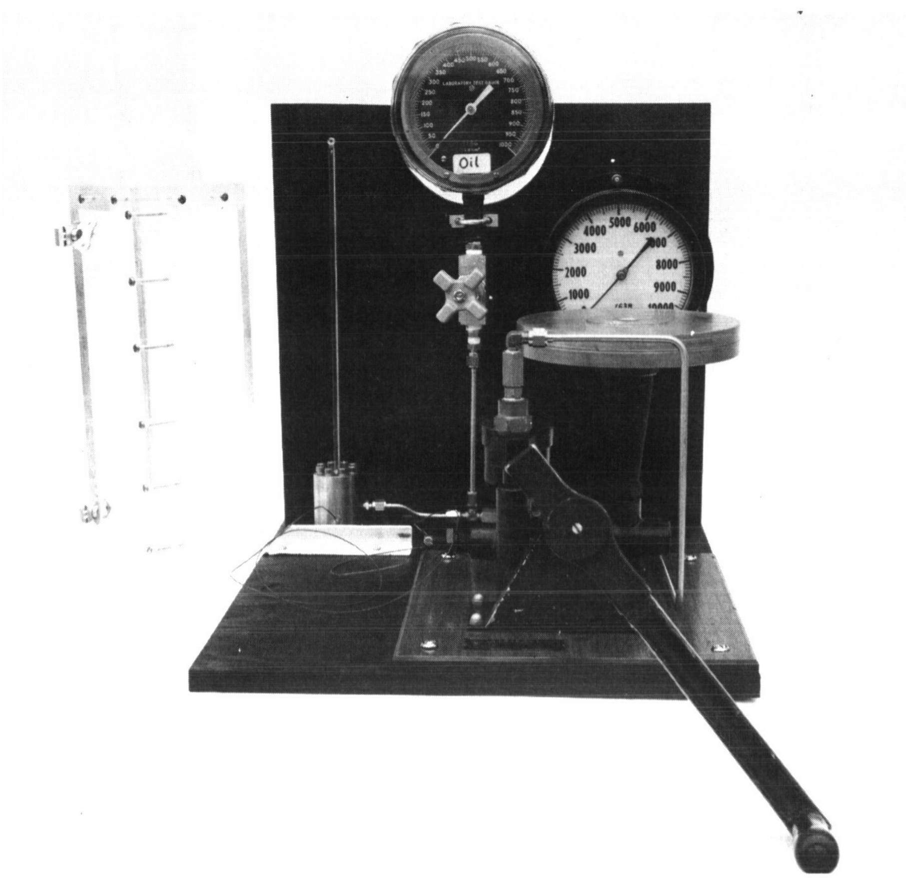

Fig. 1. Hydrostatic calibration fixture

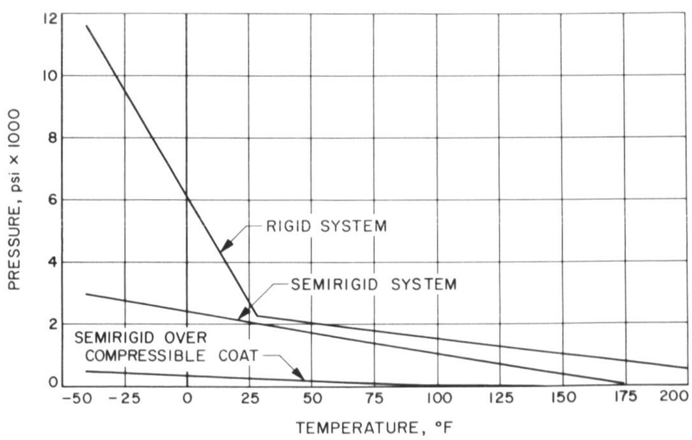

Fig. 2. Pressure vs temperature curve for three encapulation systems

STERILIZATION OF IMPACT LIMITERS

NASA Work Unit 186-58-13-04-55
JPL 384-85701-2-3510
E. C. Bernett

OBJECTIVE

The broad objective of this program is to evaluate the effects of sterilization on materials which may be used for the construction of Voyager Lander type of impact limiters. Previous studies in connection with the Ranger program showed that balsa wood is a particularly attractive material for limiter applications. There are indications, though, that balsa may be seriously affected by the sterilization processes specified for the Voyager landers. The specific purpose of this program, therefore, is to determine the effects of sterilization on the energy absorption capability of balsa, and to investigate any other variations that might be important from the standpoint of impact limiter capabilities.

TEST PROGRAM

Initial efforts in this program were directed towards a better definition of the problems that might be encountered from subjecting balsa to the Voyager thermal sterilization treatment. It was expected that exposure to the dry heat cycles would be particularly critical.

Samples were obtained and the energy absorption properties of the various batches of wood were established as a basis for comparison. These checks were made on samples in the as-received condition and also after pretreatment (by vacuum or heat) to remove residual moisture from the wood. Samples were then exposed to heat sterilization cycles at 125° and 145°C for 498 and 108 hr, respectively. These runs were made on open samples and also on samples sealed in close fitting capsules. The latter runs were meant to simulate a balsa limiter enclosed in a hermetic cover. The energy-absorption properties of the exposed samples were determined and compared with those obtained as the basis. In addition, weight and dimensional changes and other effects were noted.

As a parallel effort to the evaluation of sterilization effects, some work was done on a moisture replacement for balsa. Some moisture in balsa is desirable as it tends to make the crushing behavior of the wood more uniform. Moisture content, however, changes with the environment and is reduced to zero by heat sterilization. More stable substitutes for moisture have been studied and some tests on samples impregnated with a silicone resin were carried out.

All the test results obtained to date are summarized in Table 1. Some discussion of these preliminary results and some supplementary information is given in the following section.

DISCUSSION OF RESULTS

The performance of Voyager Lander type of impact limiters may be judged on the basis of specific energy (Ke) absorbed during a landing, the mean crushing stress of the limiter material, the relative uniformity of the crushing stress, and the thickness efficiency of the system. The specific energy is expressed in ft lb/lb, and the

higher this value the better, since overall weight can be minimized. The crushing stress is directly proportional to the impact deceleration level, and therefore lower values are more desirable. Also, the crushing stress should remain relatively constant so that the deceleration rate is uniform. The thickness efficiency of an energy absorbing material is the ratio of total deformation to original length of the sample and, of course, this should be close to unity so that the deceleration may be distributed over the maximum distance possible.

The various parameters described above can be evaluated from simple crushing tests carried out in a loading device which can record the applied force versus displacement curve. The specific energy is readily calculated from the area under this curve.

The specific energy (Ke) absorbed by the balsa samples in the as-received condition was normally about 20,000 ft lb/lb. In one batch of material, a number of very low Ke values (down to 12,600 ft lb/lb) were obtained. There was no outward visual evidence which could account for this, hence, the batch was not used for any further tests to evaluate the effects of sterilization. The scatter in Ke values of balsa, however, is recognized as a serious problem, which will have to be resolved if this material is used in the fabrication of impact limiters.

When moisture is completely removed from balsa wood, the Ke value is significantly increased; however, the crushing behavior is very erratic as evidenced by the higher value of the maximum-to-minimum crushing stress ratio. The samples often split during the crushing cycle. The maximum dimensional change produced by removal of moisture was about 0.010 in./in.

Samples exposed to dry heat sterilization cycles showed a drop in Ke, with the effect being more pronounced in the case of the longer cycle at the lower temperature. Crushing stress tends to be particularly erratic, weight losses up to 17.1% were noted, and sample shrinkages of 0.002 and 0.029 in./in. (parallel and perpendicular to grain, respectively), were observed. Also, nearly all of the samples split during the compression test indicating that transverse strength is significantly reduced.

Sterilization of samples in sealed capsules reduced the Ke values by almost 50%. Weight losses of up to 19.5%, recorded when the reaction products were released from the capsule, are further evidence that the balsa was seriously affected by this treatment. Further work on methods of sterilizing balsa in this way seems unwarranted at this time.

The performance of balsa samples in which the moisture was replaced with a silicone resin was not changed significantly. The resin did not reduce the amount of degradation which occurs during exposure at 145°C, and also it did not prevent readsorption of moisture when the samples were exposed to the atmosphere.

FUTURE WORK

The future for this program includes the following:

1. The study of degradation mechanisms that occur during heat exposure of balsa will continue.

2. Further attempts will be made to find a suitable replacement for the moisture present in balsa.

3. The correlation between structure and mechanical properties will be investigated further so that it might be possible to select material with more uniform properties.

4. Additional sterilization treatments will be carried out in accordance with the latest Voyager specifications so that the degree of degradation may be more closely defined.

5. The comparison of balsa with other limiter materials will continue, and the study of sterilization effects will be switched to the better material should one be found.

Table 1. Effects of sterilization on balsa wood

Condition	Density lb/ft^3	Moisture, %	Energy absorption properties: Mean crush stress, psi	Max. stress / Min. stress	Thickness Efficiency	Ke, ft lb/lb	Weight change, %	Shrinkage, in./in. Min	Shrinkage, in./in. Max	Volume change, %
As-received	6 to 9	7	1200 to 1700	1.25 to 1.85	0.77 to 0.81	18000 to 23000	...	...	...	...
Vacuum dried R.T./10^{-5} Torr/18 hr	6.5	0	1400	2.20	0.85	25000	-8	0.002	0.010	-2
Oven dried 145 °C/6 hr	7.8	0	1400	2.30	0.84	22000	-6	0.001	0.007	-1
Heat sterilized 145 °C/108 hr	8	0	1450	1.8	0.83	22000	-9	0.002	0.022	-2
Heat sterilized 125 °C/498 hr	6.8	0	1000	2.5	0.88	18000	-16	0.003	0.029	-4
Sealed and heat sterilized 145 °C/108 hr[1]	6.5	4	600	1.9	0.85	14000	-11	(4)	(4)	(4)
Sealed and heat sterilized 125 °C/498 hr[2]	7.0	4	775	1.8	0.84	13500	-18	(4)	(4)	(4)
Impregnated 5% silicone resin	7.3	0	1250	2.5	0.86	21300	-2	0.001	0.012	-2
Impregnated 11.5% silicone resin[3]	8.1	0	1640	2.2	0.84	24600	+5	0.002	0.010	-2
As above, then heat sterilized 145 °C/108 hr[4]	7.7	0	1220	2.1	0.88	20100	-1	0.002	0.015	-2

NOTES:

[1] Max pressure rise was 141 psig.

[2] Max pressure rise was 147 psig.

[3] Single test — all others typical values from at least three tests.

[4] Not determined.

STERILIZABLE ELECTRICAL SOLDERED AND WELDED JOINTS

NASA Work Unit 186-58-13-05-55
JPL 384-85001-2-3570

R. F. Holtze

OBJECTIVE

The objective of this work unit for the long-range period is to determine the effects of sterilization treatments on the various material combination joints that are soldered or welded for connections in electronic equipment and to develop improved joining methods or more compatible material combinations in the deficient areas.

Additional work will be done to investigate the metallurgical stability of typical welded joints between component leads and various candidate nonmagnetic, interconnect materials. This work is part of a program for development and qualification of a nonmagnetic interconnect material to be used for welded cordwood modules in a sterilization environment.

STERILIZATION EFFECTS TESTING OF SOLDERED AND WELDED JOINTS

Status

Contract 951069 to the Hughes Aircraft Co. covering an investigation of sterilization effects on soldered and welded joints was completed October 9, 1965. This work also included an investigation of sterilization effects on the solderability of various lead materials.

The test data have been analyzed and preliminary determinations made on the action to be taken in developing improved joining methods or more compatible material combinations.

Test Results

Detailed results of the program completed under Contract 951069 are covered in a JPL internal document. A summary of these results is as follows:

The investigation of sterilization effects on soldered and welded joints involved the preparation and testing of 1362 soldered joints of 11 different types, including both stranded and solid conductors joined to connector cups and bifurcated terminals. A total of 834 cross-wire weld joints of 7 different material combinations was also prepared and tested. All solder and weld joint types were tested and examined before and after thermal sterilization of 108 hr at 145°C. Testing consisted of:

1. Ultimate strength.
2. Electrical resistance.
3. Electrical testing during vibration.
4. Ultimate strength after vibration.
5. Stress-rupture strength.

6. Metallurgical examination.

7. Electron probe microanalysis.

Based on a statistical analysis of the test results, it was concluded that there was no significant change in the ultimate strength or electrical resistance of either the soldered or welded joints due to the effects of a thermal sterilization process (Table 1). Neither the metallurgical examination nor the electron probe microanalysis showed any degradation in metallurgical structure or in the extent of gold diffusion which could be attributed to thermal sterilization. However, the stress-rupture strength tests on the connector cup soldered joints pointed out that steady-state loads of only 10% of the ultimate strength (of the joint at 25%) were enough to cause short-term solder joint failures under thermal sterilization conditions.

The investigation of sterilization effects on solderability of leads involved the preparation and testing of 320 specimens, of which 64 were metallographically examined and 256 were solderability tested. The specimens for this program included nine different solid and stranded wire conductor materials, two types of connector cups, and two types of bifurcated terminals. Specimens were solderability tested (by dipping in a solder pot) and examined metallographically before and after three treatments: (1) thermal bake-out, (2) heat sterilization, and (3) ethylene oxide decontamination. Photomicrographs at 1000X magnification were taken of all specimen types before and after treatment. All solderability test results were analyzed statistically.

Based on the test results, it was concluded that thermal bake-out, heat sterilization, and ethylene oxide decontamination had very little effect on the solderability or metallurgical integrity of the specimens tested (Table 2). Although a few specimen types did exhibit certain effects due to either thermal bake-out or heat sterilization, these effects were minimal and could be attributed to either unrelated causes or to factors which could be corrected in production usage.

Future Plans

Additional work will be done (1) to develop improved joining methods, (2) to determine sterilization effects on more suitable temperature resistant materials, and (3) to evaluate sterilization effects on additional material combinations. A work statement will be issued and a contract for this follow-on work negotiated.

NONMAGNETIC INTERCONNECT MATERIALS

The activities under this work unit have been limited to the preparation of a statement of work for an outside contract for this effort. This contract is expected to be let in the third quarter of FY 1966. The initiation of this contract is dependent upon completion of another task; that of proving the feasibility of at least one nonmagnetic interconnect material.

The scope of this work is intended to cover a large range of welded samples. Lead materials and lead sizes will be variables in this study. The basic plan is to determine any changes in the weld metallurgy caused by sterilization. These changes will be analyzed by metallographic techniques accompanied by electron beam and/or X-ray analysis where necessary.

Table 1. Summary of test results on soldered and welded joints.

Types of joints / Various tests	Effect of thermal sterilization						
	Ultimate strength	Electrical resistance	Stress-rupture strength	Electrical test during vibration	Ultimate strength after vibration	Metallurgical examination	Electron probe microanalysis
Solder Joints							
1.1.1 Stranded conductor to Cinch connector cup	none	decrease	decrease	none	none	none	-
1.1.2 Stranded conductor to Bendix connector cup	decrease	decrease	decrease	none	none	none	-
1.2 Stranded conductor to solder coated bifurcated terminal	decrease	increase	-	none	none	none	-
1.3.1 Gold-plated copper to solder-coated bifurcated terminal	increase	none	-	none	none	none	none
1.3.2 Solder-coated copper to solder-coated bifurcated terminal	decrease	increase	-	none	none	none	-
1.3.3 Gold-plated Dumet to solder-coated bifurcated terminal	none	none	-	none	none	none	-
1.3.4 Gold-plated Kovar to solder-coated bifurcated terminal	none	none	-	none	none	none	-
1.3.5 Gold-plated nickel to solder-coated bifurcated terminal	none	decrease	-	none	none	none	-
1.3.6 Bare nickel to solder-coated bifurcated terminal	none	decrease	-	none	none	none	-
1.4 Gold-plated copper to gold-plated bifurcated terminal	decrease	none	-	none	none	none	none
1.5 Resistor lead to solder-coated bifurcated terminal	none	-	-	none	none	none	-
Weld Joints							
1.1 Bare nickel to Inco	none	none	-	none	none	none	-
1.2 Gold-plated nickel to Inco	none	decrease	-	none	none	none	-
1.3 Gold-plated Kovar to Inco	none	increase	-	none	none	none	-
1.4 Gold-plated Dumet to Inco	none	none	-	none	none	none	-
1.5 Gold-plated copper to Inco	decrease	increase	-	none	none	none	none
1.6 Solder-coated copper to Inco	none	increase	-	none	none	none	-
2.0 Gold-plated Kovar foil to itself	decrease	none	-	none	none	none	-

Table 2. Summary of test results.

Type of specimen	Effect of different exposures					
	Thermal bake-out		Heat sterilization		ETO decontamination	
	Solderability test	Metallurgical examination	Solderability test	Metallurgical examination	Solderability test	Metallurgical examination
A. Gold-plated copper wire	none	none	--	--	--	--
B. Gold-plated Dumet wire	none	none	--	--	--	--
C. Gold-plated Kovar wire	slight passes[a]	none	--	--	--	--
D. Gold-plated nickel wire	none	none	--	--	--	--
E. Bare nickel wire	none	none	--	--	--	--
F. Gold-plated Dumet wire with nickel undercoat	fails[a]	none	--	--	--	--
G. Gold-plated copper wire with nickel undercoat	none	none	--	--	--	--
A. Stranded conductor	--	--	none	slight[b]	none	none
B. Brass, copper-plated, gold-plated connector cup (Cinch)	--	--	none	none	none	none
C. Brass, copper-plated, silver-plated, gold-plated connector cup (Bendix)	--	--	none	slight[b]	none	none
D. Solder-coated copper wire	--	--	none	none	none	none
E. Solder-coated bifurcated terminal	--	--	significant drop[c]	none	none	none
F. Gold-plated bifurcated terminal	--	--	none	none	none	none

[a]Refers to solderability specification which requires minimum of 95% coverage.

[b]Structural change questionable; could be caused by other factors; and was not 100% repeatable.

[c]Attributed to protective coating applied over solder coating prior to heat sterilization.

STERILIZABLE CONNECTORS, WIRES AND CABLING ACCESSORIES

NASA Work Unit 186-58-13-06-55
JPL 384-85801-2-3570

L. M. Michal

OBJECTIVE

The objective of this work unit is to determine design criteria for development and selection of multipin electrical and RF connectors, electrical wires and RF cables, and accessory connector and cabling components applicable to sterilizable spacecraft assemblies. The current fiscal year activities will attempt to finalize the design and qualification testing requirements. A number of detail design specifications and qualification test specifications will be prepared as models to guide the development and testing activities.

ELECTRICAL CONNECTORS

The JPL Contract No. 951329 has been signed by both parties. A delay was instituted before release of the contract to Hughes Aircraft Company of Culver City. The Voyager project for which the proposed sterilizable components would be developed has indicated needs for significant changes to the sterilization requirements. It is anticipated that parts and components would be subjected to more numerous ethylene oxide (ETO) decontamination and heat sterilization cycles in type approval verification. So that the proposed tests would be meaningful and compatible to Voyager and since the testing has not been started, it was considered advisable to delay the action until the significance of the proposed changes have been appraised. Meanwhile, we have drafted proposed changes to the decontamination and sterilization procedures into the work statement in anticipation of the new decontamination and sterilization specification, JPL Spec. VOL-50503-ETS which is currently being issued. It appears that a surplus of available test specimens may result from proposed reductions of testing at only one decontamination temperature. The surplus specimens will be made available for the qualification tests, task 2 of the FY 1966 activity to follow.

At the recent National Symposium on Spacecraft Sterilization, sponsored by NASA at the California Institute of Technology on November 16 to 18, 1965, the author, in conjunction with Al Fitak and Robert Holtze, presented a paper on Sterilizable Electronic Packaging, Connectors, Wires, and Cabling Accessories. The writer reported the plans to conduct the study of heat sterilization and ETO treatments on connectors, wires, and cabling accessories. A review was made of the anticipated problem areas which were related to possible effects of ETO and heat on the parts.

WIRES, CABLING ACCESSORIES, RF CONNECTORS, AND RF CABLES

The Request for Proposal No. 337388 to study the effects of ETO and heat on wires, cabling accessories, RF connectors and RF cable parts and components was issued to six selected companies. Two responded with a marginal comprehension of the study requirements. One of the offerers has been selected but not notified. No negotiations have been conducted, but the program has been delayed for the same reasons as the proposed changes to the Voyager sterilization requirements. A draft of a proposed revision to the task work statement has been prepared.

The cognizant engineer visited the Martin Orlando facility and discussed their wire and cabling experiences with H-film, a polyimide insulated hook wire that is being examined by JPL as a sterilizable candidate.

Martin had two reasons for dropping the use of H-film insulation. One was that it was not compatible to nitrogen tetroxide, a fuel of the Titan rocket and two, it was too expensive to be universally applied on the Titan program. Although they also had some minor problems of utilization, the weight saving of the insulator is an attractive feature for its selection as a spacecraft candidate. In conjunction with a layer of fluorinated ethylene propylene (FEP), the wire becomes a more tolerable part than the use of straight H-film.

FUTURE AND PLANNED ACTIVITIES

It is anticipated that the sterilization studies for the connector and wire parts of the subject sterilization work unit will be conducted in the third quarter of fiscal year 1966. Thereafter, the qualifications test program task 2 should commence. All of the detail design specifications and detail qualification test specifications will be written and first drafts will be issued to support the study.

SPACECRAFT AND CAPSULE EQUIPMENT DEVELOPMENT (186-68)

PLANETARY ENTRY AND LANDING STRUCTURES

NASA Work Unit 186-68-01-01-55
JPL 384-60101-2-3530
A. C. Knoell

OBJECTIVE

The purpose of this work is to study and develop the application of materials and devices with high energy-dissipating capabilities to the protection of spacecraft and/or capsules during terminal landing. The broad objectives of this unit are two-fold. First is the mathematical prediction of the response of energy dissipators subject to material and system constraints, and second is the evaluation of pertinent energy-dissipating properties of various materials and devices. The current fiscal year objectives include the theoretical determination of stress wave effects on the response of energy dissipators and the evaluation of balsa wood, plastic honeycomb and metal honeycomb as energy-dissipating media.

THEORETICAL RESPONSE PREDICTIONS

To mathematically predict the effect of high velocity impact on the response of an energy dissipator, an in-house theoretical investigation was undertaken to study impact induced pressures, velocities, stress fronts, and shock phenomena. As a first approximation of the impacting energy dissipator, a laterally unconfined uniform bar of initial velocity, v_0, and mass density, ρ_0, was considered. A general stress-strain function $\sigma = \sigma(\epsilon)$ was used to represent the equation of state of the material. The governing equations of the mathematical model were obtained from the principles of conservation of mass and momentum. By changing end conditions, the following cases were simulated:

1. Bar impacting a rigid surface at rest at one end and free at the other end.

2. Bar impacting a flexible surface at rest at one end and free at the other end.

3. Bar impacting a rigid surface at rest at one end and attached to another bar of the same initial speed at the other end.

4. Bar of elasto-plastic property with infinite strain hardening impacting a rigid surface at rest at one end and attached to a rigid mass of the same initial speed at the other end.

The results of this investigation are in preparation for a release as a JPL Technical Report, On the Impact Induced Stress Waves in Long Bars, which should be available late in FY 1966 or early FY 1967.

MATERIAL EVALUATION PROGRAMS

Balsa Wood

Testing and data reduction have been completed in an in-house program to resolve the effects of environment on the response of balsa wood as an energy dissipator. A brief summary of the scope and details of effort including preliminary results were published in SPS 37-34, Vol. IV.

In general, it has been found that at ambient temperature and atmospheric pressure the amount of energy dissipated per pound of balsa wood (specific energy) increases almost linearly with decreasing moisture content. Also, under conditions of atmospheric pressure and natural (as-received) moisture content, the specific energy capacity of balsa increases with decreasing temperature. The actual response of 6 and 10 lb/ft^3 balsa as determined in the program is given in Fig. 1. These relations are based on test data which have been normalized to exclude specimen batch differences. A similar type of response has been determined for balsa wood tested at atmospheric pressure and zero moisture content. Finally, the specific energy-dissipating capacity of unmoisturized balsa wood has been found to increase with decreasing temperature when tested in a vacuum. In all cases the variation in crushing stress has been found to be similar to that of specific energy.

The results and conclusions developed in this program, including a detailed description of test specimens, equipment, instrumentation and procedure, will be presented in a technical paper entitled "Environmental Effects on the Response of Balsa Wood as an Energy Dissipator." A draft of this paper is currently being prepared. Publication is scheduled for the beginning of the fourth quarter of FY 1966.

Plastic Honeycomb

On July 1, 1965, a contract was awarded to the General Electric Company, Valley Forge, Pennsylvania, in the amount of $102,000 for the continuing development of plastic honeycomb as an energy-dissipating medium. This contract represents a follow-on program to the effort completed by G.E. under JPL Contract 950564.

The present investigation is primarily concerned with the determination of the effect on response of:

1. Double curvature.
2. New resin systems applied to specimen manufacture.
3. Multiple dipping of resins during honeycomb fabrication.
4. Improved cell bonding techniques and/or adhesives.
5. High-velocity impact.
6. Temperature after heat sterilization of specimens.
7. Gross column buckling of specimens.

Long lead times for specimen procurements have resulted in only preliminary test data; satisfactory reduction and evaluation are still pending. The contract is scheduled for completion during the first quarter of FY 1967.

Aluminum Honeycomb

A statement of work has been prepared as a basis for formulating a contract to determine the response of doubly curved aluminum honeycomb as an energy dissipator. The scope of effort basically includes fabricating and statically testing a total of 27 specimens of three densities and four different curvatures, reducing and evaluating the test results, and preparing a final report.

This effort represents a pilot program to establish feasibility of fabrication and generate limited response data on doubly curved aluminum honeycomb. It is expected that the results will serve as a basis for further development effort provided energy-dissipating efficiencies comparable to balsa wood and plastic honeycomb are obtained. Contract performance is estimated at 6 mo and a cost of $25,000 or less.

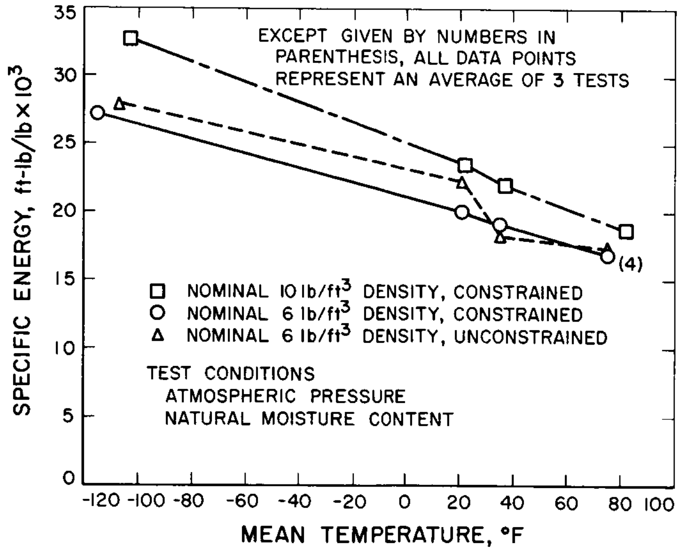

Fig. 1. Specific energy vs mean temperature

ELECTROMECHANICAL ACTUATOR DEVELOPMENT

NASA Work Unit 186-68-02-03-55
JPL 384-60401-2-3440
G. S. Perkins

OBJECTIVE

This work unit was undertaken to advance the state of the art of actuators used in spacecraft control systems. It includes investigations of the actuation devices as well as components required in these devices for attitude control, autopilots, and articulation control systems.

MICROTHRUSTERS STUDY (MINIATURE ROCKET MOTOR)

This is a study effort to investigate the use of the solid propellant electrical thruster (SPET) as an attitude control actuator. The contract with General Electric at Valley Forge for this study was modified at the request of General Electric to increase the scope of the work at no increase in cost, in return for an increase in time. This was done in order that General Electric could include in their final report the results of extra work performed on this problem under company funding.

The analytical problems mentioned in the previous report have been solved. They are concerned with the understanding and operation of the SPET motor. In addition, of the possible propellants previously identified, the one selected is phosphonitrylic iron chloride. It is a high-temperature synthetic lubricant developed by DuPont Research for high-temperature gyroscope spin bearings. This fluid has the closest conformity to the requirements of any evaluated. The characteristics of this propellant will be more completely discussed in a future JPL SPS volume.

There are two electronic firing configurations being considered for the SPET motor. The first, the one in common use, makes use of a cold cathode trigger tube (Fig. 1). This firing scheme has two problems:

1. The use of the switching tube adds to the resistance and inductance of the circuit requiring power.

2. The tubes available are not able to handle the large currents and rapid current rise of the SPET. As a consequence their life is shortened. G.E. has a SPET switching tube currently under development that will tolerate this load demand and not be subject to breakdown.

The second circuit (Fig. 2) eliminates the trigger tube by applying the same small energy pulse which previously went to the grid of the switching tube across two small triggering electrodes in contact with the propellant film. This causes the propellant to vaporize in a small amount which is sufficient to switch the main discharge across the exploding accelerating electrodes. This mode of firing greatly increases the efficiency of the engine.

There is one problem involved with this mode of firing. After about 200,000 pulses the contaminant residue from the fuel builds up on the primary electrodes

causing a general deterioration of motor efficiency. Continued firing leads to motor shorting. This phenomenon does not occur with the trigger tube configuration of firing.

A preliminary draft of the final report is expected in late December 1965 and the final draft is to be submitted shortly thereafter. It is planned to initiate subsequent work in this area in the last half of FY 1966.

ANTENNA ACTUATOR

New concepts and components are being investigated to reduce the weight and improve the efficiency of an actuator suitable for movable antennas, instruments, sensors, or camera platforms. The parts for the first experimental model are being fabricated and procured. Assembly activity will soon be in progress.

PASSIVE SOLAR VANE ACTUATOR

Analysis of the solar vane actuator operation on the Mariner C flight to Mars has revealed the following two pieces of information:

1. The spacecraft torque noise level was far higher than anticipated.
2. The actuator dead band (i.e., backlash) was too great for rapid response.

Future applications can be satisfied by an engineering modification to the existing actuator. Therefore, no AD effort is seen as required at this time. Effort on this task has therefore ceased until such time as further activity is indicated.

BRUSHLESS POTENTIOMETER

Since there were approximately ten common, high quality, potentiometers on the Mariner C flight to Mars with no indication of difficulty, this effort is no longer deemed necessary. Hence, no further efforts are planned.

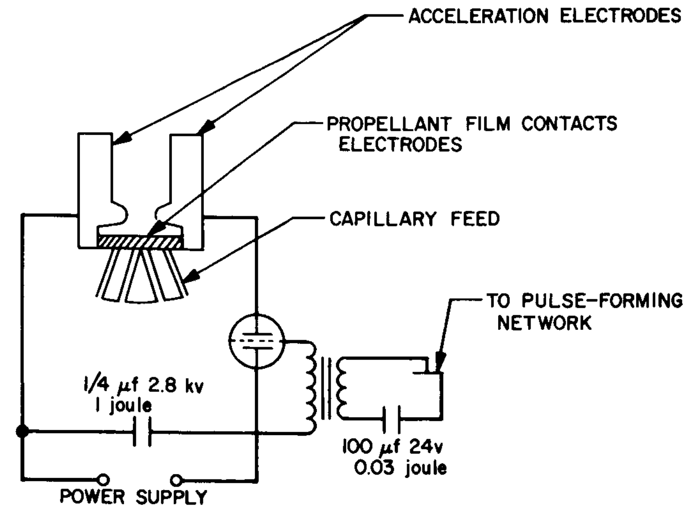

Fig. 1. Circuit with cold-cathode trigger tube

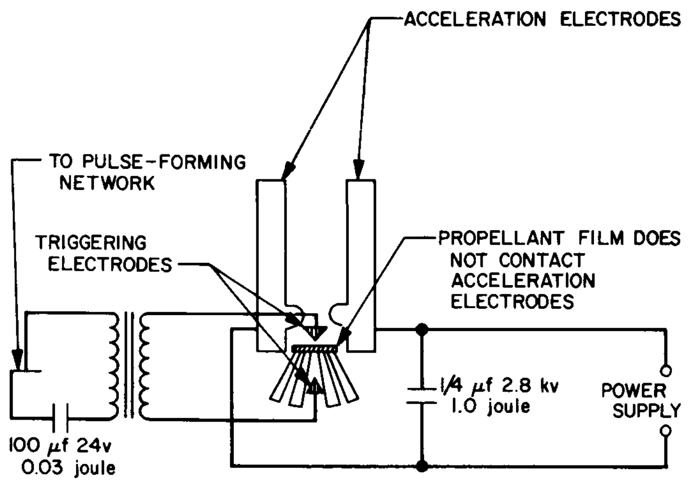

Fig. 2. Circuit eliminating cold-cathode trigger tube

LUNAR AND PLANETARY HORIZON SCANNER

NASA Work Unit 186-68-02-04-55
JPL 384-60501-2-3440
J. M. McLaunchlan

OBJECTIVE

The lunar and planetary horizon scanner (LPHS) program concerns the development of a long-life, infrared horizon sensor with no moving parts. This sensor would be useful on Voyager type of missions for providing information as to the direction of the local vertical of a planet from an orbiting spacecraft. The development is being made with the aid of an industrial contractor (Barnes Engineering Company) for design and fabrications, with JPL providing support in various design areas as well as detailed testing and evaluation.

PROGRESS

During the latter half of CY 1965, contractor design of the LPHS has continued. The contractor was directed to modify the design to a new configuration which will result in a significant reduction in size and weight of the sensor. The contractor has also been directed to submit a proposal for incorporation of a custom integrated circuit into the breadboard electronics constructed in the present design phase. Difficulties have been experienced by the contractor in obtaining responsive quotations from qualified semiconductor manufacturers for the fabrication of this device, and while this problem is now resolved the schedule for completion of the design phase has been delayed until April 1966.

LPHS Configuration

Studies have been conducted in the use of an LPHS type sensor for pointing the planetary science platform on the Voyager spacecraft. These studies, using the maximum and minimum values of orbit parameters anticipated indicate that a maximum LPHS field of view (FOV) for a single head to be approximately 60 deg. The LPHS performance specifications have accordingly been relaxed from 90 to 60 deg FOV. This will allow the contractor to use a refracting type optical system instead of the present Schmidt type reflecting optics. The change in configuration together with a smaller detector array will result in the size of a single sensor head being reduced from 7 x 7 x 6 in. to 2.5 x 2.5 x 2.5 in., a reduction of size of a factor of 20! It is anticipated the weight reduction will be a factor of approximately 4.

This new configuration has necessitated some redesign. A contract modification for $9,938 of additional funding for this redesign was issued September 24, 1965.

Integrated Circuit Signal Commutator

Previous studies and tests had indicated that the Metal-Oxide-Semiconductor Field Effect Transistor (MOS FET) would give as good a performance as the presently used neon-lamp photoconductor for the required low-level signal commutation. The MOS FET offers considerable potential advantages in the area of small size, simplicity, and reliability. The present design is accordingly based on the use of this device. To gain the most effectiveness, the MOS FET's are used in a custom integrated circuit with the MOS FET's leads spaced to correspond with the detector

leads on 0.025 in. centers. Since the design and fabrication of this integrated circuit is a long-lead-time item and since it would be desirable to obtain a significant quantity of this component for qualification testing, the contractor was requested to propose procuring this circuit during the design phase. The contractor has subsequently accomplished the following:

1. Prepared extensive specifications and test procedures for the custom circuit MOS FET's.
2. Visited semiconductor device manufacturers that are potential bidders.
3. Solicited a proposal from vendors.
4. Submitted a proposal to JPL as a result of this activity.
5. Recontacted the vendors originally indicated, at JPL's direction, to obtain additional responsive proposals for the manufacture of these devices.
6. Resubmitted the proposal to JPL.

These activities altogether have required six months of effort on the part of the vendor and have delayed the completion of the design phase until May, 1966.

FUTURE PLANS

A contract modification will be made in the third quarter of FY 1966 to cover: the custom integrated MOS FET devices, the procurement of a subcontractor by the contractor to aid in the electronic packaging design and some increased costs due to the delay in completion of the design phase. It is estimated this modification will be for approximately $75,000.

A contract will be negotiated in the fourth quarter of FY 1966, for fabrication of two sets of flight prototype sensors based on the design now being completed. This will be incrementally funded with approximately $75,000 of FY 1966 funds and $75,000 of FY 1967 funds.

IMAGE TUBE DEVELOPMENT

NASA Work Unit 186-68-02-05-55
JPL 384-60601-2-3440
E. S. Davis

OBJECTIVE

This work unit has as its objective the further development of the electrostatic image dissector tube. Increased electron lens resolution, deflection linearity, and null stability are the specific improvements to be incorporated into the tube.

INTRODUCTION

This task is a continuing effort carried out in conjunction with CBS Laboratories to improve the basic all-electrostatic image dissector. Our experience with applying the basic image dissector in the Mariner IV Canopus Sensor is being fed back into the second-generation electrostatic image dissector. Improved image tube characteristics are required for high-performance star sensor and approach guidance planet sensor applications.

BASIC IMAGE DISSECTOR CONTRACT

The final task, a life test of two tubes, on the basic contract (JPL 950054) is to develop the electrostatic image dissector,has been completed, and CBS Laboratories is in the process of writing the final report on this phase of that contract.

THE WIDE ANGLE SHORT ELECTROSTATIC IMAGE DISSECTOR (WASEID) CONTRACT

Work on this contract is complete and the contractor is in the process of writing the final report. The two required tubes have been delivered to JPL but in-house evaluation is not possible due to the diversion of technicians to other tasks. The first tube has been returned to CBS to check some resolution data which now appears to be erroneous.

The CBS data on this contract indicates that only one major goal has been achieved. Deflection drift (or hysteresis) has apparently been eliminated by the incorporation of an improved Schlesinger deflection yoke which minimizes exposed dielectric surfaces and is integrated with the focusing anode. This part is called a "drift-free integrated anode deflection cone." CBS has tested many tubes, not all on this contract, for deflection drift and none has shown any detectable drift, either with time or temperature (range 20 to 65 °C).

The other area of major concern on this contract was improvement in electron optical resolution. Figure 1 shows that we are short of our design goal in the outer region of the photocathode, which represents 50% of the cathode area. The new focus electrode designed using analog plotting techniques has not achieved the desired goal.

The deflection linearity of the tube has been measured and it is quite good (1%) on each axis taken individually. However there is a very large amount (over 10%) of "pincushion" distortion. Figure 2 shows equal potential deflection curves for the

WASEID. This distortion is correctable, using techniques established for deflections in cathode ray tubes.

IN-HOUSE TEST FIXTURE DEVELOPMENT

Progress in the development of a test fixture for the WASEID has been slowed by diversion of manpower to the Surveyor Project. The unit is about 75% complete and requires about two man-months of work to complete. The new fixture handles the curved faceplate of the new image dissector and provides for automatically scanning the photo-cathode for defects.

FUTURE ACTIVITIES

We are in the process of writing a new contract with CBS in which a new deflectron will be designed to reduce deflection defocusing. In addition, each tube fabricated is to contain an electron optical experiment where electrode geometrical parameters will be systematically varied with the goal of improving electron optical resolution. These tubes will utilize the bi-alkali photocathode developed on the high temperature image dissector program (NASA 186-58-02-02-55). A life test (two tubes at 165°F and two tubes at room temperature) has been included in the program to evaluate the possible improved (compared to cesium antimony S-11) stability and extended operating temperature range that should characterize the bi-alkali photocathode image dissector. This move will also aid the high-temperature photocathode image dissector program by exercising the contractors staff in processing bi-alkali tubes and the standardization should promote efficiency in both programs.

Efforts to reduce the overall size of the image dissector have been temporarily abandoned due to lack of a firm requirement and adequate funds. A shorter tube is still desirable for sensor packaging efficiency.

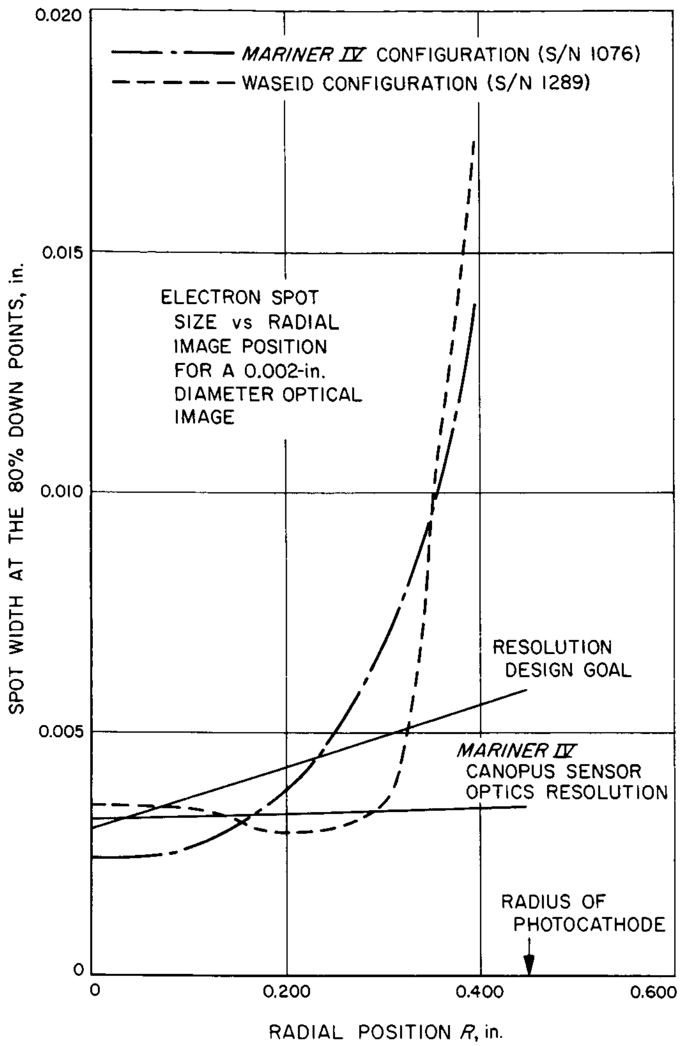

Fig. 1. Design goal

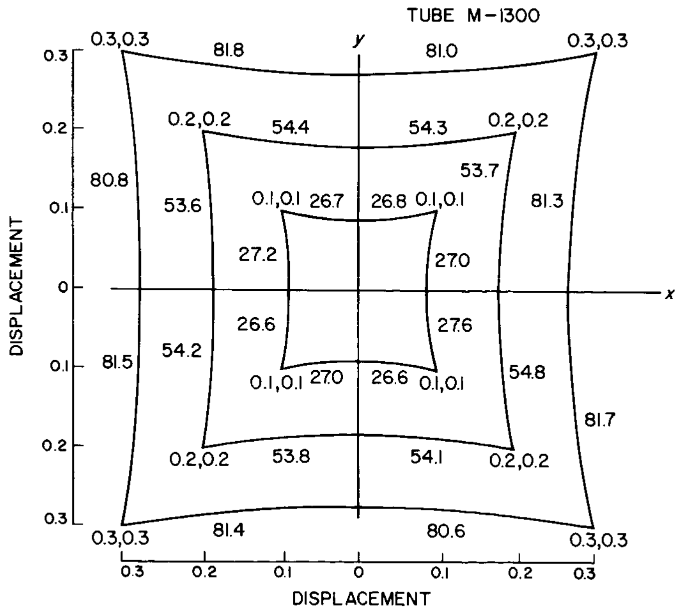

Fig. 2. Potential deflection curves. Figures indicate total deflection voltage ÷ 2 equipotential deflection curves

FLIGHT COMPUTERS AND SEQUENCERS ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-08-55
JPL 384-63701-2-3410

G. R. Hansen, Jr.

OBJECTIVE

The goal of this work unit is to develop and evaluate logical organizations, circuits, and components for advanced spacecraft Central Computer and Sequencer (CC&S) subsystems. The CC&S requirements considered include those for the spacecraft bus as well as orbiter or lander capsules. The longer range objectives are concerned with defining and instituting tasks leading to the development of CC&S subsystems for complex planetary missions requiring substantial increases in operating life in more severe environments.

LOGICAL ORGANIZATION

A comparative study of timer versus memory oriented CC&S systems has been concluded with the results favoring the memory oriented system. The system and logical design of a two-memory limited command structure sequencer has been completed. This system was developed utilizing the *Voyager* mission profile as a typical performance requirement (cf. SPS 37-36, Vol. II). Two memories are utilized to avoid extra registers and a two operand address command structure is provided for ease of programming sequencer type operation. Hour, minute, and second time resolution is available for event times.

An additional task started was the reformulation of the machine to utilize inhibit core logic techniques. A significant reduction in components (excluding ferrite cores) should be realized through this technique as compared to the "magnetic-module" logic previously contemplated.

The logical design of an Inhibit Core Logic mechanization of the two-memory sequencer is now 50% complete and will be finished during the next period. This design will be verified by simulation techniques to assure the completeness of the design. The *Voyager* mission will be used as the basic functional requirement. Programs utilizing the command vocabularies of the two-memory machines have been written for the sequencing operations in launch, midcourse, cruise, Mars orbit injection, capsule release, occultation, platform pointing, and orbiting experiment control.

The effectiveness of various redundancy schemes are being studied with the principal aim of developing an applicable method to protect sequencers from the effects of single catastrophic failures.

CIRCUITS

Hybrid integrated circuit-magnetic elements have been used to construct a 29 stage counter with 10 readout stages, a 15 event matrix and 10 relay drivers. This system has undergone over 2000 hr of life testing to date with 500 hr of this time at 20% low voltage. During the next period, when 3000 hr have been accumulated, temperature extreme tests will be started. During the last quarter of FY 1966 temperature and voltage tests will be combined.

An adaptive clock system which adjusts to the rotational period of a spin stabilized spacecraft has been developed and is now under test. The system is mechanized with integrated circuits manufactured by Sylvania. A second adaptive clock system will be constructed as components become available from Westinghouse. Changes in the parameters of the integrated circuits used in the first clock system will be ascertained through a continuing testing program. The Sylvania system will be rebuilt using a new breadboard construction technique developed here, wherein the integrated circuits are temporarily mounted four to a PC board. The boards in turn are inserted in multipin connectors, and all interconnection can be made on the connector pins. The method accommodates either flat-packs or transistor-can IC's which can be reused after the breadboard has served its purpose.

Magnetic-logic modules (20 binary counters, 10 counter readouts, 2 shift registers) have been received from the Data Science Corporation and work has started to test these devices under severe shock environments. Three binary counters and three counter readouts have been tested for survival at shock levels up to 3,000 g with impact velocity greater than 200 ft per sec. All six circuits survived and the modules are being dissected to ascertain the effects of shock on the internal structure. Various magnetic devices, such as memory core planes, current steering switches, and logic rope arrays, will be developed and tested for high impact systems during the next period.

COMPONENTS

Two contracts were negotiated with Sippican and Hughes for the welding of magnet wire. Hughes completed work on the feasibility of using lasers for welding. The process was not consistent but yielded excellent weld results when consistency could be maintained. The Sippican work will be started and completed during the third quarter of FY 1966. Sippican will investigate a more conventional thermocompression welding method.

During the next period, component selection will be started for moderate to high impact (2000 to 10,000 g) survivable systems to be utilized on planetary capsule missions.

ADVANCED SCAN PLATFORM

NASA Work Unit 186-68-02-09-55
JPL 384-61901-2-3440

T. Kerner

OBJECTIVE

The goal of this effort is the development of a scan platform system to provide a mounting base for scientific instruments. A lightweight, low-power, high-reliability scan system capable of search acquisition, track, and/or scan is sought.

SYSTEM MECHANIZATION

As shown on Fig. 1 the platform subsystems shall be comprised of a planet sensor and/or programmer, a controller, a motor, and an actuator. The sensor used to control the platform position is an infrared horizon scanner now under development by Barnes Engineering under contract from JPL. The complete lunar and planetary horizon sensor (LPHS) consists of four optical scanning heads (a pair for each axis) and the signal processing electronics. Each head contains a 10- x 81-deg array of detectors. The instantaneous field-of-view of each detector, neglecting image aberrations, is 0.25 x 10 deg. The arrays consist of 90 detectors spaced 0.9 deg apart on center, giving the total array size of 10 x 81 deg. A scan in one axis consists of simultaneously sampling the detectors in two opposing heads, starting with the detectors farthest apart and proceeding towards the nadir. If the planet is positioned on the optical axis of the LPHS, both heads will give a concurrent signal indicating planet presence as the horizon is crossed, and no error signal will be generated. If an error exists, one head will provide a presence signal first, and the number of detectors sampled until the opposing head also indicates planet presence is proportional to the error. The scan period is 100 millisecs defining the frequency with which the error signal is updated. Figure 2 shows the scan geometry of the horizon scanner.

Two alternate approaches in mechanizing a platform that shall satisfy the science requirements are being explored. One approach, and from the standpoint of mechanization the simpler one to implement, is shown in Fig. 3. The horizon-scanner output is processed by logical circuitry in a manner where any error, regardless of its magnitude, drives the motor one step for each scan period in a direction dictated by the polarity of the error. The transfer functions of the several blocks are shown in Fig. 4. The horizon scanner is represented by a nonlinear amplifier fed into a sampling switch and followed by a zero-order hold circuit. The stepper motor is represented by an integrator, sampler, and zero-order hold circuit. The boom mounted platform is characterized by a second-order system transfer function.

This type of system defines the maximum stepping rate of the motor as 10 steps/sec. From the orbital consideration, as presently formulated, the maximum tracking rates required from the scan platform are in the order of 0.2 deg/sec. Allowing for a 100% margin to accommodate the system dynamics an incremental rate of 0.04 deg/step can be realized. The system was simulated on the analog computer. A parametric study of the effects of the structural characteristic variations on the system performance was made. Both the resonant frequency and the damping ratio were varied. The system was stable for all cases run.

The proposed mechanization of the system is shown in Fig. 5. Head "A" and head "B" of Fig. 5 refer to the two complimentary optical scanning heads that comprise a one-axis sensor device. A signal output from head "A" followed by a delayed output from head "B" corresponds to some error in the platform orientation from the local vertical. From Fig. 5 an output from head "A" actuates the associated flip-flop which in turn inhibits the other flip-flop from being energized for the remainder of the scan and also actuates a "one shot", whose "on" time is of a duration enabling the stepper motor to be driven one step. A simultaneous output from both heads, corresponding to no error, is inhibited. A new scan resets both flip-flops.

An alternate scheme of mechanization being investigated is shown in Fig. 6. This is a proportional system using an induction motor instead of a stepper motor to drive the platform. Figure 7 shows the transfer functions of the several blocks. Figure 8 shows how the output signal of the two heads is converted into an analog signal which after filtering is utilized to drive the induction motor.

This scheme has been set up on the analog computer, and we are now reviewing cases for the same platform characteristics as for the stepper motor to be able to compare the performance characteristics.

FUTURE EFFORT

Breadboarding of the two alternate approaches will be completed. The complete breadboard system will be dynamically tested in the celestial facility simulation. As part of this task the system will be required to track a simulated planet. Wherever possible the actual hardware will be used. A special problem is envisioned in the development of a rebalance servo that shall null out the gravity effects during the simulation.

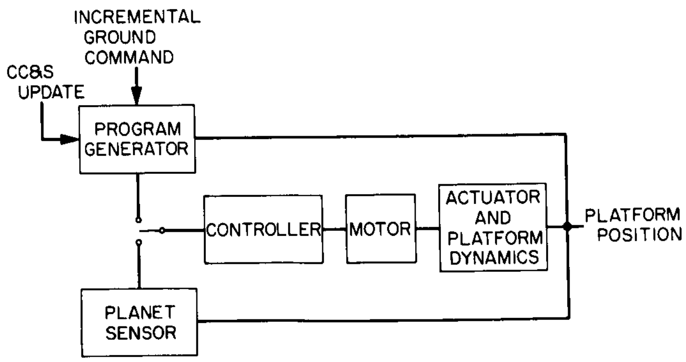

Fig. 1. Scan platform subsystem

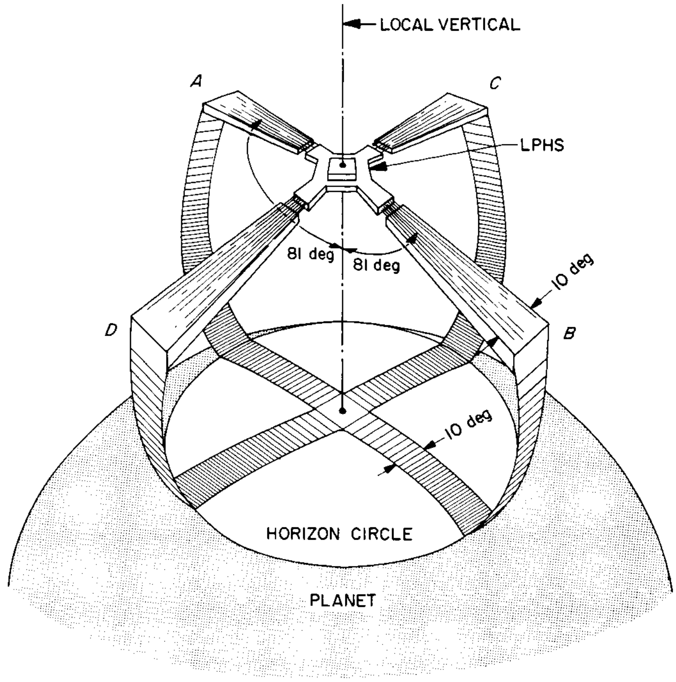

Fig. 2. Scan Geometry of the LPHS

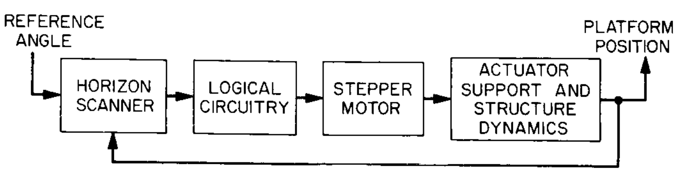

Fig. 3. Functional block diagram of stepper-motor-driven platform

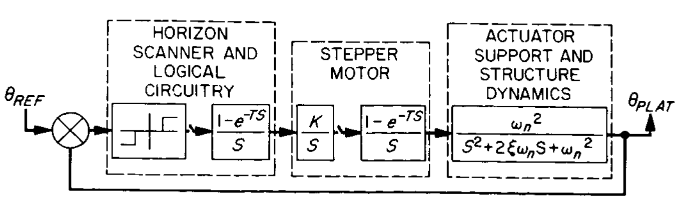

Fig. 4. Analytical block diagram of stepper-motor-driven platform

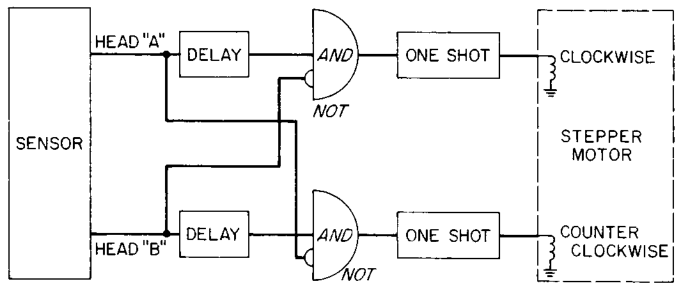

Fig. 5. Mechanical block diagram of the scan platform

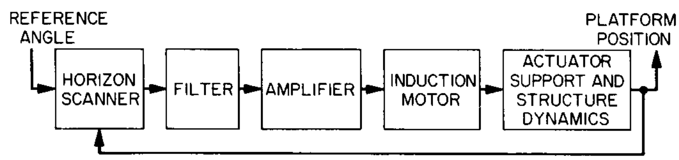

Fig. 6. Functional block diagram of induction-motor-driven platform

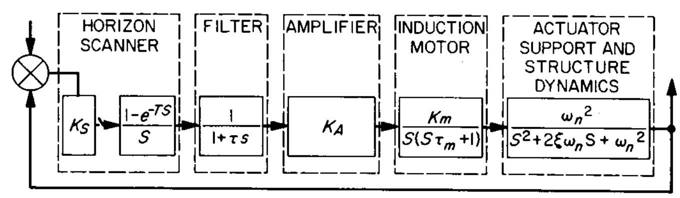

Fig. 7. Analytical block diagram of induction-motor-driven platform

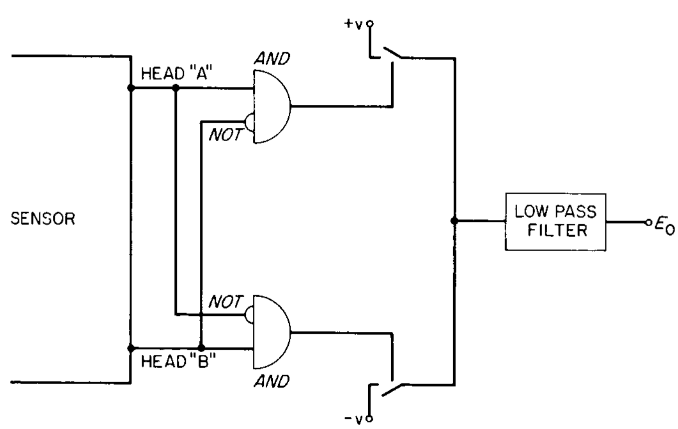

Fig. 8. Horizon scanner output conversion to analog signals

SPACECRAFT GUIDANCE RADARS

NASA Work Unit 186-68-02-14-55
JPL 384-61001-2-3360

C. E. Gilchriest

OBJECTIVE

The objective of this work unit is to develop a well-founded radar capability and to develop radar prototypes for use on future spacecraft. The immediate objective is to learn, analyze, and classify guidance radar techniques for use on board spacecraft as altimeters and velocity sensors.

ACTIVITIES

Analysis of Surveyor Radar and Doppler Velocity Sensor

The objective of the analysis is twofold. The first is a complete and thorough analysis of the RADVS in order to understand the operation, assets, and liabilities of the system in its current mechanization. The second objective is the theoretical ground work for a guidance radar more generally useful than one designed solely for lunar landings. The analysis of the system is divided into four main sections, which are:

1. Analysis of the radar return signal. This section investigates both the total reflected power and the spectral shape of the return.

2. Analysis of the RADVS receiver transfer function. This section treats the system as linear from the radar front end through the cascade of filters to the frequency discriminator input.

3. Quasi-static AFC loop analysis. In this section, the analysis assumes the VCO output is short-term independent of the input.

4. Evaluation of RADVS performance margins. This section investigates acquisition and tracking performance for both sinusoidal and gaussian signals.

Work on the above topics has considerable bearing on the general landing radar research. The main accomplishments are listed below.

1. An exact expression for total return signal power as a function of range and beam incidence angle was derived. For application to RADVS, an approximation valid for narrow beams greatly simplifies the computational effort.

2. The return signal power equation described in (1) also provides a means of calculating the spectral shape of the return signal. The equation contains an integral over the RF illuminated surface. If the radar is moving, each incremental area sees a different relative velocity, and hence, imparts a different doppler frequency shift to the incident energy. In order to generate a spectrum, it is necessary only to sort each incremental contribution according to

its frequency shift. A computer program was written to perform this operation. Since its completion in mid-December, test runs have not yet yielded satisfactory results.

3. The linear system analysis of the RADVS receiver/tracker makes two assumptions. First, the detector is a linear mixer. Detailed analysis to confirm or deny this assumption has not yet been done. Second, the only limiter in the system model does not affect its linearity. This assumption is derived from the block diagram and the nature of the tracking-loop frequency discriminator.

4. The basic element in a doppler radar is the frequency tracker. Analysis of RADVS tracker has met with some success. The average value of the discriminator output is proportional to the sign and magnitude of the doppler shift. The proportionality factor displays threshold behavior at about 0.0 db SNR at the discriminator input. This analysis assumes a sinusoidal signal with gaussian non-white noise as an input. A more realistic signal model is a narrow band gaussian process with non-white gaussian noise. Preliminary results from this model show no major changes.

5. The results of items 1, 3, and 4 allowed evaluation of the RADVS performance margins. Since the SNR at the discriminator is crucial to system performance, the SNR margin over that required for loop operation was used as a figure of merit. With the aid of tabulated data, the margin may be calculated for any altitude, surface beam incidence angle and velocity along the beam.

The General Guidance Radar

Some of the RADVS work was expanded in scope for application to more general guidance radar studies.

1. The radar signal return and spectrum calculation program was generalized to apply to an arbitrary guidance radar system. It is capable of calculating the auto- and cross-spectra for multiple beams. The user must specify the spacecraft attitude, altitude, velocity, antenna orientations, and functional descriptions of their patterns. The program computes the desired spectra, derives altitude and velocity information from them, and calculates errors with respect to the values along the beam axes. The program is not ready for general use as it is still being debugged.

2. Some modifications to the RADVS system configuration are being considered. One would eliminate the range beam, which is colinear with the spacecraft roll axis. The other 3 beams would be identical FM-swept radars. Both range and velocity information are available from each axis. Spacecraft attitude, altitude, and velocity could be calculated by an on-board computer. The concept is to simplify the radar at the expense of additional computing capability.

Determination of Guidance Radar Functional Requirements and Needs

Since Mariner IV has shown the atmosphere of Mars to be quite small, other means than parachutes and drag devices must be considered to aid in landing of heavy payloads on its surface. Our experience with guidance radar for such a purpose has been only with the Ryan RADVS system. The objective of this task is to determine if the needs and functional requirements are the same as the RADVS or whether entirely new concepts are necessary.

The task is to be accomplished by actively soliciting aid from the Systems and the Guidance and Control personnel to:

1. Determine the system functional requirements and constraints.
2. Perform tradeoff studies for the various modes and mechanizations.
3. Outline a functional specification of the guidance radar system.
4. Perform signal-to-noise ratio-and-error analysis for the guidance radar system.

Progress on this task has been slight due to the lack of manpower.

Investigation of Pulse Radars for Spacecraft Guidance

The objective of this task is to investigate a radar mechanization for soft landing on a planet (other than the current Ryan RADVS system) to determine if it has greater potential in application and accuracy and fewer problems.

This task will be accomplished through two different routes: one route will be to assume identical requirements as those of the RADVS system and investigate mechanizations utilizing pulse techniques rather than CW techniques. The second route will be to investigate alternate mechanizations utilizing pulse techniques to implement the functional requirements determined in the task above.

Thus far, a study of the available RADVS documents has been undertaken to determine the motivation behind the present method of attack.

A literature survey has been initiated to accumulate information on the latest pulse radar techniques.

Analysis has been started for a single-beam pulse radar having an arbitrary angle of incidence to a smooth surface plane.

It is felt that the general guidance radar program mentioned earlier in this report which computes the return spectrum for the single frequency, sinusoidal incident signal can be adapted for use in the pulse radar case. Information obtained from the study will be used to determine preferred methods of extracting from multi-beam systems, desirable parameters such as range, velocity, and attitude.

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PLANET TRACKER

NASA Work Unit 186-68-02-15-55
JPL 384-64401-2-3440

D. G. Carpenter

OBJECTIVE

The objective of this task is to develop a planet tracker capable of directing instruments toward the center-of-planet visible light. Such a sensor would be applicable for antenna pointing.

The mechanical configuration of the planet tracker is based on shadowing techniques such as those used for sun sensors on the Mariner and Ranger spacecrafts. The detectors employed are solid state cadmium sulfide photoconductors, working into a bridge circuit that provides zero-volts error signal at null.

The planet tracker will be capable of operating from sources as dim as one foot candle and as bright as the sun (12,600 foot candle) without moving parts or protective sun shutter.

PLANET TRACKER STATUS

Testing of the engineering evaluation model was completed December 30, 1965. Data analysis is now underway with final report completion expected by January 31, 1966.

From recent information obtained, it has been determined that there is no apparent immediate application for this type of planet tracker on JPL associated projects. It is therefore intended that no further work will be undertaken on this task after the completion of the final report.

The final report will be written to include possible applications of the tracker along with its operating characteristics, limitations, and suggestions for variations. The report will be directed to other agencies who might have a use for a light-weight, solid-state, simplified center-of-illumination planet tracker of medium accuracy.

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OPTICAL SENSORS TECHNIQUES

NASA Work Unit 186-68-02-19-55
JPL 384-64601-2-3440

L. F. Schmidt
E. S. Davis
D. G. Carpenter
D. S. Herman

OBJECTIVE

The objective of this task is to advance the state of the art of optical sensors techniques, including lens design, testing of advanced optical sensing devices, investigation of detectors, and signal processing techniques for star tracker.

LENS DESIGN — L. F. Schmidt

Objective

The objective of this work unit is to further develop a computer lens design program.

Improvements Made to Lens Design Program

Changes have been made in the program to allow usage of aspheric polynomial surfaces for both ray-tracing and design operations.

A separate program was written for determining the relative sensitivity of spot size to each design variable. This was found to be more practical than modifying the design program to produce this information.

Program changes were also made to allow the assigning of an individual weight for each color used. Previously all colors were automatically weighted equally.

Another change was made to allow a weight of 1.0 or 0.0 to be assigned to the RMS-x and RMS-y spot size values. When a weight of 1.0 is assigned to both the RMS-x and RMS-y values, then the program functions as it did previously. This new feature has been extremely helpful on the star tracker lens design in which the RMS-x value is minimized while the RMS-y value is smeared by a cylindrical lens surface.

It is expected that the least squares minimization technique employed by the program will be modified to reduce the computer time required for design operations. When this change is made it is also the logical time to rewrite the program into FORTRAN language. It is now written largely in machine language which will not be compatible with the new computer equipment which JPL is planning to implement in approximately two years. If written in FORTRAN, the program could then be used by other organizations that do not have the necessary computer equipment to use the program in its present form.

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Lens Design Report

The lens design report (JPL TR 32-790) has been submitted to the JPL Reports Group. Some additional data will also be generated to bring the report up to the latest changes in the program.

Star Tracker Lens Design

Smearing of the star image was first accomplished by using a cylindrical surface adjacent to the image dissector tube face. This produced satisfactory smearing on axis, but it became less pronounced as the image was removed toward the edges of the field of view. This same result occurred when two crossed cylindrical surfaces adjacent to the image dissector tube face were used. The use of one cylindrical surface on the front or back of the first optical element (as shown in Fig. 1) smears the image satisfactorily at any position within the field of view. With this configuration, however, the color correction is no longer adequate and alternate materials are being investigated to solve this problem.

Infrared Lens Design

The program is being used for some design work on an optical system for the lunar and planetary horizon scanner (NASA Work Unit 186-68-02-04). The design work is being done to assist the subcontractor, who is responsible for the design and fabrication of the planet scanner.

Collimation Lens Testing

When tested the collimating lens for the Sun simulator was found to have a collimation accuracy of approximately 30 sec, which is inferior to the predicted accuracy of 12 sec. Although a tolerance study of this lens was not made it is expected that fabrication errors would account for this difference.

Antireflection Coating

Coatings of magnesium flouride have been deposited using JPL facilities. However a satisfactory technique for controlling the thickness has not yet been developed because of higher priorities commanded by other projects.

ELECTRON OPTICAL DESIGN PROGRAM — E. S. Davis

Objective

The goal of this activity is to develop a digital computer program to be used in the analysis and design of electron optical systems. This effort is in support of the wide angle image dissector program where off-axis electron optical resolution needs improving.

Progress

Little progress has been made on this subtask because the project engineer at the contractor left before completing the first phase of the program (which was calculation of the fields). The effort has been brought in-house under the JPL Programming Section where liaison with the Celestial Sensor Group will be easier.

Future Activity

A flow chart of the desired program is shown in Fig. 2. Effort in the coming period will be concentrated on: (1) completing the work in the areas of inputing electrode parameters and calculating the potential function, (2) inputing the initial conditions of electrons, (3) calculating trajectories, (4) calculating the spot size and (5) evaluating the programming cost and ultimate production-running cost of the automatic design function which is proposed for this program.

PHOTODETECTOR PERFORMANCE IMPROVEMENT — D. G. Carpenter

Objective

The purpose of the work unit is twofold: first, to establish pertinent and reasonable requirements for cadmium sulfide photodetectors for spacecraft use, and second, to obtain photodetectors meeting these necessary requirements.

Vacuum-Deposited Photodetectors

Shown in Fig. 3 is a sample of the detector obtained under the current Autonetics contract (funded under FY 1965, NASA 186-68-02-16). The cell is a developmental device and therefore is not in any final configuration or package. The Autonetics contract is 90% complete with the final report due January 21, 1966.

Preliminary data from the work being done by Autonetics under the evaluation phase of this contract looks favorable. Comparative analysis between the Autonetics cells and commercially available cells indicate the Autonetics cells to be superior both in dc stability and uniformity between cells. However this is preliminary data, and a thorough analysis must wait until their final report is received.

The Autonetics cells have survived all the sterilization tests imposed on them.

Null Stability Tests

Several null stability tests have been performed in-house on Clairex 705L Photodetectors. The results show some fairly large drifts or null shifts when used in the shadowed configuration. Null shifts as high as 6 deg of arc have been observed when subjected to long-term temperature cycling up to 200°F. However, further testing is being initiated with both the Autonetics cells and Clairex cells to formulate some solid results.

Future Plans

After a detailed analysis is performed on the volumes of data obtained from the Autonetics contract and in-house work, a specification will tentatively be written outlining in detail the requirements for a Cadmium Sulfide Photoconductive detector to be used for deep space applications.

These specifications will be written with both the true needs of a photoconductor and the ability to obtain these desired characteristics in mind.

Following the formulation of these specifications, a contract will be let for the fabrication of cadmium sulfide photoconductors to JPL specifications. These will then be thoroughly tested and evaluated to JPL specifications.

THERMOELECTRIC INFRARED DETECTOR RESEARCH — D. S. Herman

Objective

The objective of this work is an improved thin-film thermoelectric infrared detector. This type of detector is used in the electronically scanned lunar and planetary horizon scanner (LPHS), (NASA Work Unit 186-68-02-00).

Thermoelectric Detector Research

A contract was let in November 1965 to Barnes Engineering Company for research in the above area on a level-of-effort basis for a 9-mo period. Investigations are broken down into the following areas:

1. Improve thermoelectric output of the present bismuth-antimony detectors to achieve bulk thermoelectric properties.

2. Improve thermoelectric output through the use of new materials.

3. Improve thermoelectric output through the lowering of heat losses from the hot junctions of the detectors.

4. Provide a detector capable of operation in the temperature range of -40 to 160°F and capable of sterilization (145°C for 36 hr, 3 cycles) in an inoperable state.

5. Fabricate thermopile detectors using the improved techniques and comparing them with previously manufactured detectors.

A program was decided upon for achieving bulk properties in the bismuth-antimony film detectors. The program consisted of varying the thin-film parameters of evaporation rate, substrate temperature during and after deposition, and film annealing conditions. Preliminary tests will be conducted on thermocouples rather than thermopiles for ease in performing the tests.

Barnes had done some preliminary work on their own before the contract was let. This allowed them to complete a number of important experiments since November. They have achieved bulk properties for some of the bismuth-antimony test thermocouples. They are still in the process of testing the thermocouples to see what conditions give the best results.

Preliminary work has been carried out in the area of new materials. The most promising materials appears to be various Bi_2Te_3 compounds. The compounds are not available commercially, but have to be manufactured by Barnes. This difficulty is not a handicap since Barnes has the capability. Thin films of these compounds will be evaporated and their thermoelectric and electrical resistivity properties measured to see how useful they will be as detectors.

The contract is for a period of 9 mo so that the major part of it, especially in areas 2 through 5, should be accomplished during the next six months.

SIGNAL PROCESSING – E. S. Davis

Objective

This work is directed toward improving the functional performance and simplicity of star sensors.

Activities

Several different types of signal processing techniques have been breadboarded and tested: different types of sweep, saw tooth and triangular wave; different types of intensity channel mechanization, synchronous and nonsynchronous detection; and different types of roll position signal mechanization, roll plate feedback, open loop, and modulation phase feedback loop. All of these systems have much less sensitivity to background light than the Mariner IV sensor and represent significant improvements in performance without increased complexity and in some cases with decreased complexity.

Planned Activities

This task will be completed in the next six months since one of these systems will be selected for Voyager. The signal processing techniques studied will be documented and reported in the SPS.

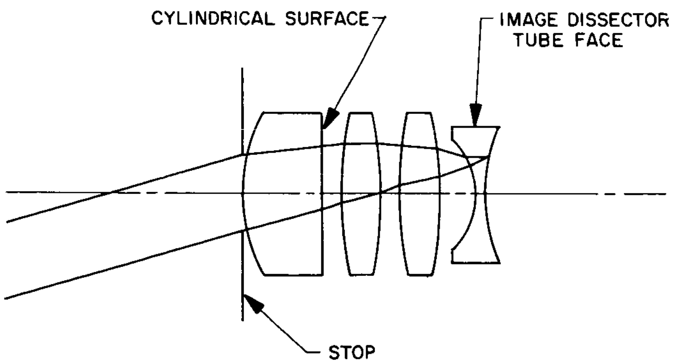


Fig. 1. Star tracker lens

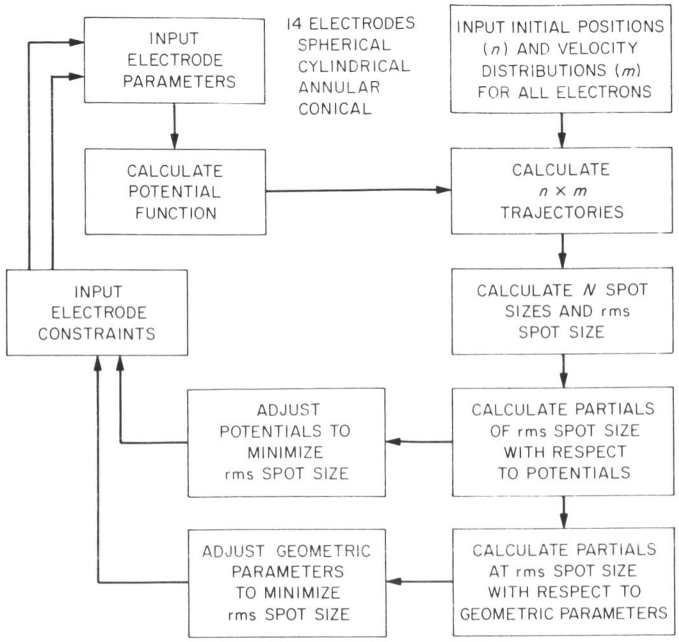


Fig. 2. Electron optical design program flow chart

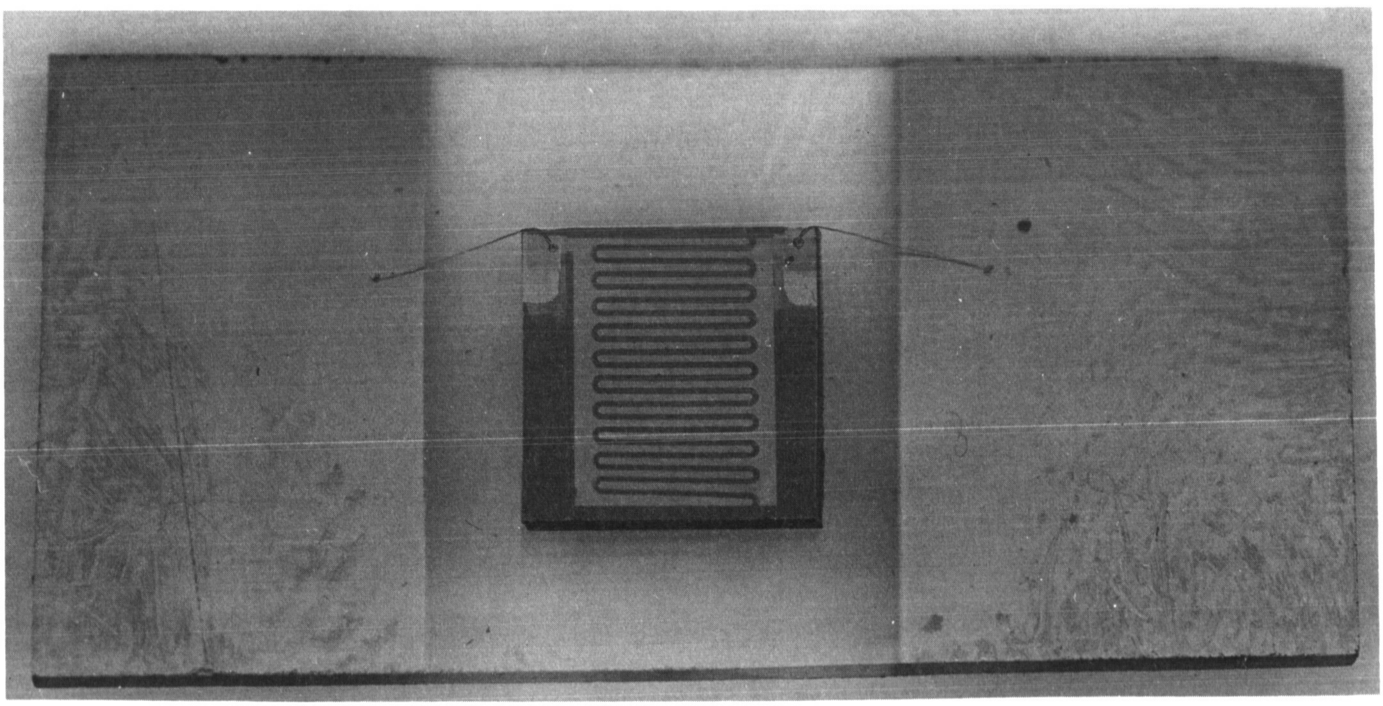


Fig. 3. Vacuum-deposited cadmium sulfide photoconductor

GUIDANCE AND CONTROL SUBSYSTEM INTEGRATION FOR FUTURE MISSIONS

NASA Work Unit 186-68-02-21-55
JPL 384-65201-1-3430

G. D. Pace

OBJECTIVE

A long-range objective of this work unit is to study the interactions between the guidance, attitude control, computing and sequencing, and power subsystems for lunar and planetary spacecraft. The information obtained is used in developing coordinated, compatible guidance and control subsystem configurations. Another objective is the development of analytical techniques with common application among several subsystem elements.

APPROACH GUIDANCE

A possible configuration for and the potential accuracy of a planetary spacecraft approach guidance system have been investigated. The system under consideration makes spacecraft-based optical measurements of the apparent position of the target planet during the last few days before the spacecraft reaches the point of closest approach. These measurements are telemetered to Earth where they are used to determine the orbit of the spacecraft relative to the target planet. This information may be used to determine and command one or more corrective maneuvers to accomplish final adjustments in the approach-trajectory parameters. This system may be necessary on missions where accuracy in determining the approach trajectory beyond that which can be obtained using Earth-based radio tracking alone is required. One type of mission where approach guidance may be required is for a close flyby of an object with a relatively inaccurately known ephemeris, such as a comet, an asteroid, or possibly Jupiter. Another type of mission is a flight to more than one object, such as a flight to Mercury that makes use of the influence of the Venus gravitational field to shape the trajectory. Here, although the ephemeris of Venus is well known, the effects of small errors in the approach for Venus are magnified many times in their effects upon approach accuracy at Mercury.

Computer programs have been developed to aid in the study of approach guidance. A program exists which considers in-plane motion and the measurement of the direction of the planet in that plane. These measurements are corrupted by random noise, a measurement bias (with drift), and a bias (with drift) proportional to the angular diameter of the planet. Accuracy characteristics of minimum-variance estimates are computed for the impact parameter (the perpendicular distance between the planet center and the asymptote of the approach hyperbola), the time of periapsis (time of closest approach), and the measurement biases. A similar program, without the drifts, has been developed (and is being documented) to analyze the accuracy of estimating the orbit in three dimensions. Accuracy characteristics of minimum-variance estimates of the dispersion ellipse in the impact plane (a plane perpendicular to the asymptote of the approach hyperbola and containing the center of the planet), the time of periapsis, and the measurement biases are computed. In addition, a program has been developed to convert data in trajectory catalogs (e.g., see JPL TM 33-100) into spacecraft angle coordinates and planet phase angle for evaluating the mounting location and tracking requirements of a planet tracker for a mission.

The following results have been obtained to date in the study of approach guidance:

1. The limiting orbit determination accuracy is controlled by the proportional bias error in finding the center of the planet. The accuracy is limited by this error until about 2 hr before closest approach when the accuracy begins to improve again. Thus, the area in sensor development which most significantly affects approach guidance accuracy is the method used in determining the planet center.

2. Previous work on approach guidance has shown that drift, a slow random variation, of the nonproportional sensor bias has a significant degrading effect on the orbit determination accuracy. A first estimate of the sensor error model yielded poor accuracy results due to the size assumed for the drift error. This led to a re-evaluation of the error model. The results of current long-term tests on a similar sensor indicated that the nonproportional bias error consisted of two parts, one constant and the other a much smaller drift. The effects of the revised error model were analyzed and the results showed that even the worst-case drift did not increase the orbit determination error significantly.

3. For drift with an autocorrelation coefficient of the form $\rho = e^{-t/\tau}$, analytic proof was derived that there is a worst-case correlation time constant, τ, that permits no improvement in the accuracy of the orbit determination over that obtained from using the last measurement alone.

4. As a result of revising the sensor error model, test data is being obtained to determine methods of processing such data to obtain more exact information on the nature of the drift error autocorrelation.

5. Studies with the three-dimensional analysis program and the current error model have shown that approach guidance orbit determination gives a significant improvement over that obtained with Earth-based radio tracking in the impact plane dispersion ellipse at one day before closest approach. Little improvement in the estimation of the time of periapsis will be obtained unless the random noise in the error model can be reduced significantly.

HANDBOOK FOR SYSTEM RELIABILITY ASSESSMENT

Final documentation of the Reliability Assessment Handbook has not been completed due to manpower reassignment to flight projects. The Handbook is scheduled for completion before the end of the fiscal year.

FUTURE ACTIVITIES

Work will be continued on approach guidance. The analysis programs developed have been used for *Voyager* studies. Use of these programs is planned for

the Jupiter probe being studied by the JPL Office of Advanced Technology Studies and for other future missions where approach guidance appears desirable. Work will continue on revising the error model and the analysis programs to incorporate improved knowledge or changes in the approach guidance system configuration, and to study alternate configurations.

During the remainder of FY 1966, work is planned to start on orbit trim guidance. Areas to be investigated are the types of measurements possible for performing orbit determination, orbital trim guidance accuracy, and guidance laws for determining maneuvers.

DEVELOPMENT OF ACTUATOR PROCESSES AND MEASURING TECHNIQUES

NASA Work Unit 186-68-02-22-55
JPL 384-64701-2-3440
J. C. Randall
R. H. Summers

OBJECTIVE

The objectives of this task are:

1. To determine the process and accuracy associated with quantitative determination of gas leaks using a helium mass spectrometer and bag technique.

2. To develop processes for measuring and predicting the characteristics for valve/nozzle designs as used in spacecraft attitude control.

The technique followed for the first objective consists of collecting the leakage gas in a sealed bag completely surrounding a charged system and detecting the increase in concentration of the helium trace gas with time by means of a helium mass spectrometer leak detector. To reduce the mass spectrometer data to a leak rate it is necessary to calibrate the bag with no helium in the test item and injecting helium at a known flow rate into the bag and measuring the time rate of helium concentration increase in the bag. A photograph of the test setup is shown in Fig. 1.

The second objective has been broken down into two tasks. First, the technique of measuring thrust/time profiles for existing thruster designs is being undertaken. With this information, cooperative effort with the JPL Aerodynamicists will result in the second task, the establishment of prediction techniques.

STATUS – BAG LEAK TEST TECHNIQUES

Initial tests were made using a bag constructed of heat-sealed polyethylene sheeting hung over an angle frame 4 in. wide by 12 in. long by 10 in. high. The system leak was simulated by resetting the calibrating needle valve to an unknown position. The leak was then determined by a ratio to the calibration leak and compared to a calibration of the unknown needle valve setting.

Calibrations were repeatable to within about 5% at a helium injection flow of 20 cc/hr and within 2-1/2% at a flow of 90 cc/hr using the large 480 ft^3 bag described. Measurements made of a 57-cc/hr leak were about 15% high; both calibration and measurement were made in about 6 hr. This does not include the time required to charge a system to its working pressure.

Without contract involvements, Hughes Aircraft Company furnished some engineering and technical help and the use of a helium mass spectrometer leak detector in some of the testing in order to gain rapid first hand information for use on the Surveyor spacecraft. A joint test report "Leak Testing the Surveyor Spacecraft Utilizing a Plastic Enclosure" is on file at JPL under re-order number 65-667. In addition, a test has been run on the Surveyor S-7 spacecraft helium system to

compare the leak rate determined by this method with that obtained from a pressure decay measurement. Preliminary results indicate very close agreement. The pressure decay method run over a four-day period showing about 52-cc/hr leakage and the bag leak test run over approximately one day showing a 50.3- to 52.4-cc/hr leak rate.

A contribution was made to SPS 37-35, Vol. IV, which includes a photograph of the test setup, calibration data and the data from the simulated tests cited.

Considerable delay was encountered when repairs and maintenance to the Veeco MS-9 Leak Detector took four months instead of the originally indicated two weeks. Some of this time was covered by use of the machine from Hughes Aircraft Company.

FUTURE WORK — BAG LEAK TEST TECHNIQUES

A final result of this activity is expected to be a guide to the design of this type of test with information on procedures, typical time requirements, bag materials and construction, and conversion of helium leak measurements to expected nitrogen leak rates for various percentages of helium as a tracer gas. The leak analysis to determine some limitations of the method and procurement of a bag of the best material and construction method to be used in a final test to show accuracy remain to be completed before the design guide can be prepared. Two types of leaks are being fabricated, one, a flattened and twisted tube and, second, a micrometer needle valve. A Bubble-o-meter for measuring low flow through the leaks has been obtained. The above equipment is being assembled to determine some of the relationships between nitrogen and helium flow through a leak.

The plan is to obtain the design of a bag, evaluation of bag materials, use of that bag in a final test for accuracy determinations, and the preparation of the design guide from an outside contractor. The final report will be the design guide and will complete this portion of the measuring techniques task shortly after the end of FY 1966.

STATUS — THRUST MEASUREMENT AND PREDICTION TECHNIQUES

The vacuum station for the thrust measurement has been modified as follows:

1. A concrete pier has been constructed which isolates the station from building noise and vibration.

2. A 50-ft^3/min vacuum pump has been purchased and installed to maintain 10^{-4} mm Hg pressure or lower during gas bearing and thruster operations.

Tests conducted to date indicate that both modifications will hold the noise and pressure at acceptable levels.

The torque motors used in the force rebalance/gas bearing system that forms a part of our instrumentation have been rewound to give greater sensitivity for the range of thrusters to be tested. In the process of calibrating these torquers, however, a problem was discovered in the gas bearing table. Several gas passages

within the bearing have become contaminated, and the table no longer operates as designed. Modifications are now being made to the restrictors to reduce their contamination susceptibility. Completion is estimated by early January 1966.

As a backup to the gas-bearing testing, a cantilever beam and strain gage approach has been initiated. Strain gages have been attached to a 1/4-in. stainless steel tube which also serves as the gas feed to the valve/nozzle. The natural beam frequency has been calculated and experimentally verified at 300 cps. In attempting to measure thrust using this technique, however, a severe 50-cps ringing has been observed which completely masks any signal due to thrust. Subsequent analysis has revealed that a 50-cps torsion mode in the beam is being excited. Beam configurations are now being looked into which have very high torsional natural frequencies in relation to the desired 300 or more cps beam frequency. Such a configuration should result in meaningful data. The successful measurement of thrust versus time for several designs will then be used to refine existing computer programs for design and prediction purposes.

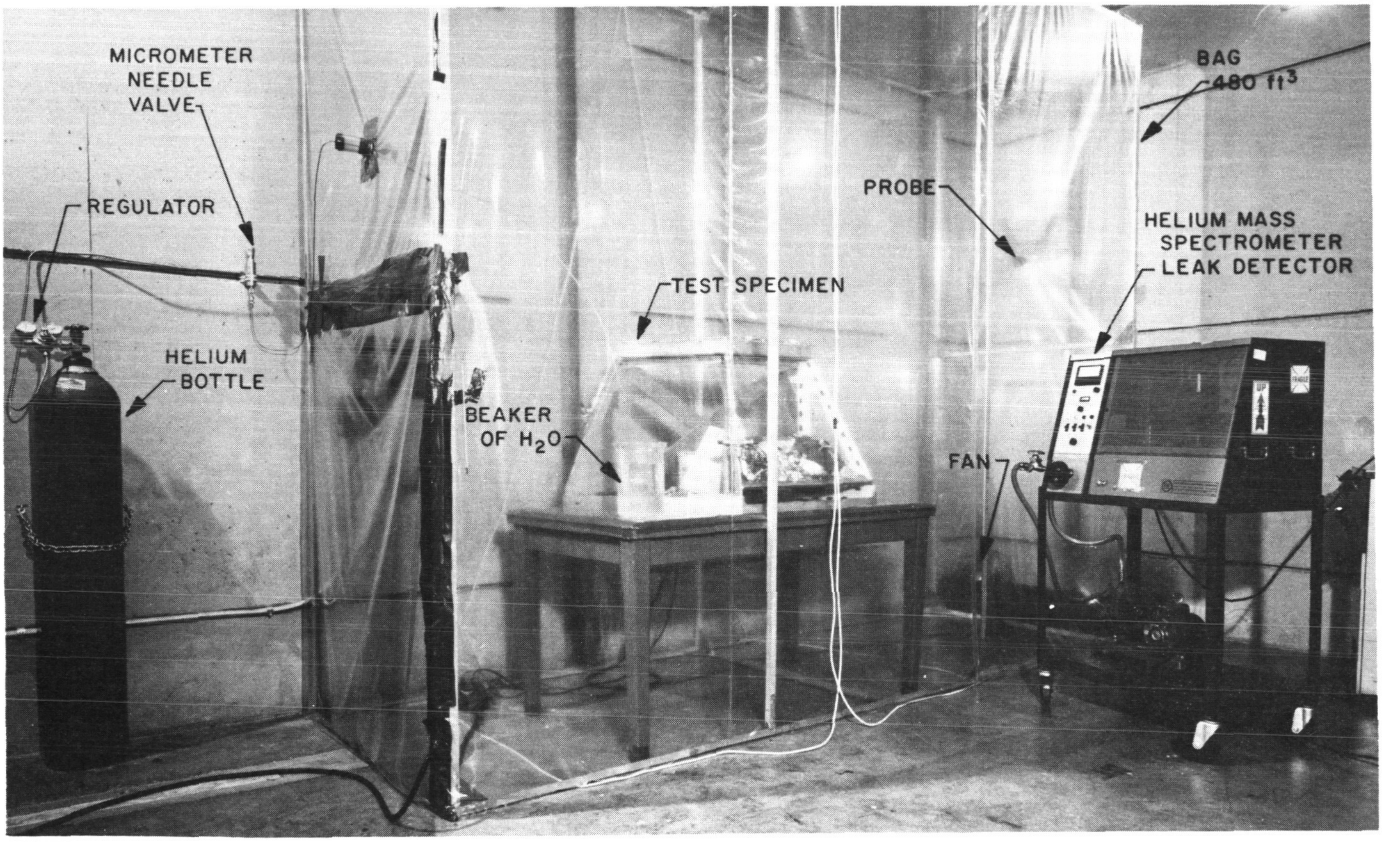


Fig. 1. Test setup

ADVANCED SPACECRAFT DIGITAL MAGNETIC TAPE RECORDER DEVELOPMENT
NASA Work Unit 186-68-03-01-55
JPL 384-60901-2-3340

OBJECTIVE

The objective of this work unit is the development of a standardized family of digital magnetic tape recorders, lighter, less power-consuming, and more reliable than those presently available, with storage capacities of 10^6 - 10^{10} bits for use in future NASA spacecraft. The effort emphasizes the reliable long-life operation that will be required by the Voyager class of planetary missions.

INCREMENTAL-MOTION TAPE-DRIVE DEVELOPMENT - W. Arens

Objective

The objective of this subtask is to determine the feasibility of transporting magnetic tape with incremental-motion in order to provide variable record and playback rates for spacecraft applications.

Status

CPFF Contract Number 951289 was awarded to Ampex Corporation on August 24, 1965 for the development of an incremental-motion tape transport. Preliminary design studies have been completed in the areas of (1) incremental-motion control, (2) capstan tape drive, and (3) signal electronics. A printed-circuit motor has been selected as the prime driver, and the design of the selected tape drive mechanism has been completed and partially breadboarded.

Future Activities Planned

The contract completion date is April 23, 1966. An incremental tape transport breadboard should be fabricated, tested, and evaluated both experimentally and analytically at that time.

HIGH IMPACT TAPE RECORDER DEVELOPMENT - W. Arens

Objective

The objective of this subtask is to determine the feasibility of utilizing a tape recorder in a hard landing capsule. The goal of the present program is to obtain a representative tape transport, subject it to 2000-g shock stresses, and evaluate the performance degradation, if any.

Status

JPL Specification Number GMY-50492-DSN and Statement of Work Number 399872 for the development of a high-impact magnetic tape recorder have been

completed. Procurement Requisition Number 399872 was completed, approved, and submitted to Procurement. A bidders' conference, originally planned for this reporting period, was delayed due to inadequate manpower availability.

Future Activities Planned

A bidder's conference will be conducted and proposals requested for the development of a high-impact tape transport early in the next reporting period. A contractor will be selected and a contract awarded within six months.

ISOELASTIC TAPE TRANSPORT EVALUATION - R. Rathcke/J. Hoffman

Objective

This is a program for detailed evaluation of the iso-drive transport, which was designed to be an exact fundamental replacement for the endless loop type transport used in the Mariner C system. It includes performance and environmental testing.

General Background

Results of performance tests conducted during the previous reporting period on the isoelastic tape transport had indicated the need for further evaluation. Abnormal flutter characteristics were noted subsequent to Mariner C type of approval testing, indicating possibility of damage resulting from such tests.

Status

During this period, a detailed dimensional analysis of the disassembled unit was completed. Several rotating components were found to be out of drawing specification. One item, the clutch assembly, also exhibited erratic operation. Pull-in voltage was inconsistent and shaft run-out exceeded tolerance by 0.0004 to 0.0008 in. New parts have been fabricated, or existing ones reworked as required to meet specification. New bearings and drive belts have been purchased. The clutch has been returned to the manufacturer for evaluation and repair.

As a result of the evaluation, it appears certain that at least some of the critical components were originally out of specification, and that the dimensional discrepancies noted were not related to the type approval test program.

Future Activities Planned

The process of reassembly is currently underway. When completed, the unit will be built to specification; and subsequent testing and comparative evaluation is planned to permit a determination of whether performance degradation is related to the test program, inherent design deficiencies, or both.

TAPE RECORDER ELECTRONICS MINIATURIZATION STUDY - J. Ponder

Objective

A laboratory study to determine the feasibility of replacing the Mariner C tape recorder electronics with integrated circuits. The Mariner C tape recorder

was chosen to provide a well-documented starting point and an existing subsystem to use as a model.

Status

Manpower limitations have made it impossible to follow the two approaches to integration mentioned in the previous report. The effort to replace discrete circuits with integrated circuits has been dropped. New circuits are under development which will operate properly functionally and will take full advantage of the linear and digital integrated circuits. This effort has been combined with the project-sponsored development of a flight tape recorder and will not be handled as a separate task in future reports.

MAGNETIC SPEED CHANGER DEVELOPMENT - E. Bahm

Objective and General Background

The currently used ac motors cannot operate properly at very low speeds. In most applications, the motor needs to be operated at a much higher speed than the device which it is driving. A speed reducer is required to match the motor to the requirements of the driven device.

The mechanical power transmitted through a rotating shaft is proportional to the product of torque and speed derived from this shaft. Therefore, the speed reducer is also a torque multiplier and allows the motor to be built for a fraction of the torque actually required.

At the present time, Mylar belt speed reducers are used nearly exclusively for spacecraft tape recorders. Lift time of these Mylar belts is limited because of the bending stress imposed during operation. For tape recorders which are required to operate during a long time in space, Mylar belt speed reducers are considered one of the limiting components.

A novel magnetic speed changer, proprietary to the Magnavox Research Laboratories, would potentially appear to overcome the problems of limited operating life. The operating principle is based upon the interaction of two toothed wheels different numbers of teeth and being magnetized by a rotating permanent magnet. All coupling is achieved by magnetic forces, and operating life is limited only by the bearings.

Status

A feasibility study for a two-stage speed reducer was performed by the Magnavox Research Laboratory on a fixed-price contract basis. The objective was to demonstrate the feasibility and generate the specifications of a magnetic speed reducer to provide electrically selectable speed ratios of 10:1 and 100:1. The speed changer was to be compatible with currently used electrically motors.

A preliminary design was made and evaluated mathematically. A simple breadboard device was built to evaluate experimentally the switching portion of the speed reducer. It was later delivered to JPL. The result of the study revealed that a switchable ratio magnetic speed reducer will be a complicated device. Designing and building it within the constraints of a spacecraft application will perhaps be

beyond the capabilities of the Magnavox Laboratories. A constant-ratio speed reducer is feasible but will be considerably larger and heavier than Mylar belt reducers. From a parallel effort by GSFC, it was concluded that the magnetic speed reducer generates more speed oscillations or flutter on its output shaft than Mylar belt reducers — though the flutter seems to be tolerable for many tape recorder applications.

A report has been received from Magnavox describing in detail the efforts undertaken and the conclusions drawn from the study. The title of the report is "A Feasibility Study of A Switchable Ratio Magnetic Speed Reducer."

Future Activities Planned

During the past three months, an idea has been generated which is expected to allow an electrical motor to operate at very low controlled speeds by means of a servocontrol system. Presently used hysteresis-synchronous motors would be operated in an asynchronous mode. A mathematical evaluation of this system indicated a possibility of operating the motor at speeds slow enough to completely avoid any speed reducer.

It is, therefore, planned to delay any further effort on the speed changer until sufficient knowledge has been obtained from the so-called "Synchronous Servo Playback System" study. If this approach should prove unfeasible or impractical, a fixed ratio magnetic speed reducer will be developed.

MAGNETIC BEARING STUDY - E. Bahm

Objective

Magnetic bearings are very attractive for space applications. Life time of such a bearing is unlimited, and speed of the rotating element can be very high. Mechanical drag is negligible for most applications. The ideal environment is the vacuum. However, many obstacles and shortcomings limit the use of this bearing. A body can be kept in suspension by magnetic forces only against very small axial and radial forces. Besides, the so-called Earnshaw's Theorem shows that a magnet placed in the field of another magnet cannot remain in stable equilibrium.

Besides these two very severe limitations and the small chance of a success, it was decided to evaluate a new concept of a passive magnetic bearing. It is intended to circumvent Earnshaw's Theorem by using two independent magnetic bearings. Each bearing itself will be unstable; but it is hoped that the two bearings are capable of stabilizing each other.

Status

A special Platinum Cobalt alloy has been procured from the Hamilton Watch Company, and the bearing system is nearly completed. Magnetizing of the magnetically very hard platinum cobalt parts caused great difficulties which were finally overcome. The bearing system is expected to be assembled in January 1966.

A so-called electromagnetic bearing has been designed and is being procured. It will operate exactly like the magnetic bearing, but will contain one electromagnet instead of a permanent magnet. This electromagnet will permit the magnetic flux and field densities inside the magnetic structure to vary and to study the performance of the bearing at different degrees of magnetic excitation.

Future Activities Planned

During the next reporting period, the magnetic and electromagnetic bearings will be assembled inside an electric motor and evaluated.

BRUSHLESS DC MOTOR - E. Bahm

Objective and General Background

DC motors have favorable characteristics for spacecraft applications. They are efficient, powerful, and can be miniaturized. Their torque-speed characteristic is ideally suited for speed control which enables this motor to operate at any desired speed. The major deterrents in applying this motor to spacecraft applications are the problems associated with the mechanical commutator.

The novel brushless dc motor has the mechanical commutator replaced by an electronic switching circuit controlled from a shaft position sensor. It displays all of the properties of a classic dc motor with a permanent magnetic field.

A development program has been outlined for a family of brushless dc motors and associated control circuits. This family of motors will consist of a basic motor design, which will be capable of being modified to meet different requirements. Several motor control circuits will be developed to further widen the applicability of this motor. It is expected to be available early in 1967.

Some specifications of this motor are:

Outside diameter	0.75 in.
Length exclusive of shaft	Between 1.15 and 3 in.
Motor torque	Between 10 and 300 gcm depending upon motor length
Speed	Between 0 and 20,000 rpm depending upon type of motor control circuit
Voltage	Between 2 and 50 v depending upon winding installed
Number of poles	2 or 4
Starting characteristic	Motor will be capable of reaching a speed of 8,000 rpm within 7 ms

Stepping characteristic	Motor will be capable of moving incrementally with up to 500 steps/sec. Stepping angle will depend upon the amplitude and duration of the applied voltage pulses.
Environmental specifications	1. Motor will be sterilizable. 2. It will not significantly change performance characteristics within the temperature range between $-10^{\circ}C$ and $+75^{\circ}C$. 3. It will meet all environmental specifications for Mariner flight equipment, type approval level. 4. Motor can be operated in a vacuum for a limited period of time.

Status

An industry survey revealed that several companies have developed brushless dc motors. All were asked to submit a technical proposal for design, development, and testing of one motor employing a proper commutating system and necessary electronics for speed control. Proposals were obtained from Sperry Farragut and Roters Associates.

Following facility and proposal evaluation by JPL personnel, both companies were asked to submit cost proposals. On the basis of their technical proposal, facility capacity, and proposed cost, Roters Assoc., was selected. It is anticipated that a contract will be placed by December 31, 1965.

Existing brushless dc motors are either not reversible or use two independent shaft position sensors, one for each direction of rotation. This is considered one of the problem areas for miniaturization of this motor. A concept has been generated for a reversible commutating system using only one shaft position sensor and is reported in a JPL internal document. Evaluation of this system will be included in the contract.

A motor torque tester has been designed and built. It allows accurate measurement of motor torque versus speed for any type of motor.

The session on brushless dc motors at the WESCON Show in San Francisco was attended.

Future Activities Planned

Activities during the following reporting period will include monitoring the design and fabrication of the prototype motor, sensor system, and motor control electronics; reviewing the design of the motor control system of the incremental motion tape drive development; and study of a German-built brushless dc motor with very interesting design features.

DRIVE BELT STUDY - J. Hoffman

Objective

The purposes to be accomplished under Contract 950899, the program to study the characteristics of polyester film drive belts, were (1) to determine belt fatigue life under conditions susceptible to statistical treatment, (2) to determine whether conditions of environment and fabrication have a significant effect on fatigue life, (3) to develop a valid method of fatigue life prediction, and (4) to determine the stress relaxation characteristics and coefficient of friction using various pulley materials.

Status

The final report on phase A, a study of the fatigue life characteristics, was completed. Seamless belts were fabricated from polyester film and tested using specially designed fixtures for fatigue life. The results were organized to provide adequate data for reliability analysis and life prediction. The fatigue life data are presented as a series of fatigue curves, each representing a given survival level at a known confidence level. The results indicate that the best fatigue life is achieved using thin, narrow belts; and that there is a strong relationship between heat-treat time and length-to-width ratio in belt fabrication. Operating factors closely related in reliability prediction are: installed stress, threading pattern, pulley diameters, transmitted torque, belt dimensions, and belt speed.

The testing portion of the program to evaluate coefficient of friction and creep and stress relaxation characteristics of polyester film drive belts has been completed. The results have established time, temperature, and installed stress as important design criteria relative to torque capacity.

A dynamometer was developed to measure the torque speed characteristics of the belts using a variety of pulley materials and surface finishes. The effects of time, temperature, and installed stress were evaluated. The coefficient of friction was determined from a point on the torque speed curve for each of the material-finish combinations tested. It was found that the coefficient of friction for each material was lower than had been previously reported, and that it was independent of the initial surface finish of the pulley. The long-term behavior of the drive belts was determined by periodically running a given test installation over a two-week period. The results indicated that the torque capacity of a system drops during this period to about 65% of its initial capacity at room temperature; however, a continuing increase in capacity was noted at 150°F.

Future Activities Planned

The final report on phase B, stress relaxation and coefficient of friction, is currently being prepared. Further investigation is indicated and is contemplated as a part of a similar evaluation of H-Film drive belts, which indicate superior life characteristics and high temperature capability. A requisition has been submitted to proceed with such a program.

MAGNETIC TAPE STUDY PROGRAM - W. Clement

Objective

This is a continuing program of evaluation and study of the electrical and mechanical characteristics of magnetic tape. The purpose is two-fold: (1) to solve specific problems and (2) to keep abreast of new developments in the industry.

General Background

Magnetic tape is the one critical element in a tape data storage system about which little can be done with regard to optimization of characteristics for a particular application. This is because tape production technology is extremely complex and costly; and spacecraft applications of tape constitute a negligible profit motive for the manufacturer. It, therefore, becomes important for JPL to conduct a tape evaluation program in considerable depth so that characteristics of other elements (heads, transports, etc.), over which control can be exercised, may be optimally matched to the tape. It is also, of course, important to be able to consider the tradeoffs in performance characteristics between the different types and brands of tape, and this capability also results from such an evaluation program.

Status

Additional samples of magnetic tape have been tested in the static friction test rig at Applied Magnetics Corporation. These included samples which had been processed with heat and vacuum at JPL. The test results indicated considerable improvement due to this processing for the specific samples involved. However, improvement of this particular tape product by the manufacturer now tends to reduce the significance of this processing.

Modifications to a Cybetronics tape cleaner are complete and performance of the device appears satisfactory. No evaluation of its effect on tape with regard to the incidence of drop-outs has yet been made.

A trip was made to Lash Laboratories in San Diego to obtain information on a new tape development involving a plated medium on H-Film backing. Evaluation samples have been ordered. A visit was also made to the Memorex Corporation in Santa Clara to discuss with Memorex and GSFC personnel a high-temperature tape development program to be sponsored by GSFC. A meeting was held at Applied Magnetics Corporation to discuss with AMC and GSFC personnel a tape friction test program.

Future Activities Planned

Efforts will be applied towards accumulating electrical performance data as well as additional frictional data on tapes.

It is expected that two new programs will be instituted shortly by GSFC. JPL personnel will assist in the technical direction thereof.

TAPE GUIDANCE STUDY - W. Clement

Objective

The purpose of this work is to make a contribution towards extending the art of digital data packing density on magnetic tape.

General Background

Analysis of the limitations in packing density reveals tape position control to be a major item especially where data is to be recovered from parallel tracks simultaneously. A study of various methods of guiding tape over the heads was instituted by a CPFF contract to the Kinelogic Corporation.

Status

Five different tape guidance systems were tested for dynamic skew and amplitude modulation. Non-return-to-zero (NRZ) recording was performed on 6-mil-wide parallel tracks for each guidance system. Acceptability criteria of 50 microins. maximum peak-to-peak dynamic skew (0.25 in. tape) and 10% maximum amplitude modulation were arbitrarily established. Three of the systems tested (crowned rollers – E, flange guidance – C2, and trough guidance – D2) satisfied these criteria. The other two systems tested (single edge guidance – C3 and groove guidance – A) did not.

The final report on this study is being studied to determine the advisability of follow-on activity.

Future Activities Planned

None at the present time.

LOW CAPACITY DYNAMIC STORE STUDY - E. Bahm

Objective

A study is being conducted to determine the device best suited for storage of between 100,000 and 1,000,000 bits of data. It is felt that neither solid-state memories nor available tape recorders are proper devices for the above capacity range. Solid-state memories are proper devices for storage of small amounts of data, but are complicated and bulky if their capacity is large. The tape recorder is a large capacity storage device but develops serious wear problems if its capacity is low. The operating life of a small capacity tape recorder, therefore, is limited.

Status

An industry survey for information on such storage devices revealed that the most feasible device for spacecraft applications seems to be a magnetic drum manufactured by IBM for the Titan missile. Indications are that this drum is more reliable than any tape recorder can possibly be. It has only one rotating part, the drum itself. It carries the recording media on the outside, while the inside is used as the rotor of the drive motor. The drum is air-floated. At continuous operation,

life time of the whole device is determined only by the electronics. The number of start/stop cycles may perhaps limit the life time but even this seems not to be a real problem in the weightlessness of space.

For a detailed evaluation of the Titan drum, a trip was made to the Federal Systems Division of IBM. It was found that this drum could be used for the application contemplated with only minor modifications. Size, weight, and power consumption are very close to that of tape recorders, but the short access time must be considered another advantage of this drum.

Though currently not available from the industry, a special tape loop recorder seems to be an alternate to the magnetic drum. This recorder would employ a short loop of magnetic tape to be stored in a bin or suspended on a series of pulleys. The tape loop will not be fabricated by splicing of magnetic tape because the best splicing technique is considered insufficient for the stress to which the loop is subjected during a long operating time. Seamless tape loops have been fabricated by using two different methods:

1. Seamless Mylar belts have been fabricated from sheets of Mylar using well-known fabrication techniques. These belts subsequently were plated with an alloy containing mostly cobalt and being proprietary to the Cambridge Laboratories.

2. Seamless magnetic belts have been fabricated from already coated H-Film sheets using the same methods as above.

The cobalt-plated belts have been evaluated using a breadboard tape transport which was built from a scrapped tape recorder.

Quality of the plating is insufficient, but probably caused by lack of experience of the vendor. Indications are that the quality can be increased simply by more careful handling during the plating process. Recording on the belt was possible though the plating was magnetically harder than the coating of ordinary magnetic tape.

The coated H-Film belts seem to have a more uniform recording surface. No damage to the recording surface from the belt fabrication process could be detected, but evaluation has not been completed yet.

Another problem area associated with low capacity tape recorders is tape wear. During many revolutions of the short loop, the magnetic coating or plating will be damaged by the heads. Tape wear can be eliminated by placing the recording heads on the uncoated side of the belt and recording through the base material. The spacing between heads and recording surface results in reduced recording density, higher recording current, and lower playback signal amplitude. Feasibility of recording through the base material was demonstrated with 0.0005-in. thick cobalt-plated belts. It was found that 600 bits/in. can well be recorded on a single track. Record current for saturation recording was approximately 50% higher than with heads in contact with the magnetic surface.

A report was written for a forthcoming SPS describing in detail the work performed until December 1965.

Future Activities Planned

Following the evaluation of the coated H-Film belts, the relative merits of the *Titan* drum and tape loop recorders will be established.

SPACECRAFT DATA SYSTEM SIMULATION

NASA Work Unit 186-68-03-03-55
JPL 384-60801-3240

M. Perlman

OBJECTIVE

The long range objective is the design, simulation, and analysis of scientific data systems by a general-purpose digital computer. A more rapid design cycle, maximation of scientific information to be delivered to the experimenter per unit hardware, enhanced reliability, and updating of system documentation are specific goals.

Within the fiscal year, the feasibility of this technique will be demonstrated by simulating the logical design of an abbreviated scientific data system and providing design support to the Capsule Data Handling System SRT Unit 186-68-03-04-55.

SIMULATION

A fixed-cost contract was awarded to the Mesa Scientific Corporation to provide a computer program that would enable a logical designer to simulate the logical behavior of a data system on an IBM 7094 general purpose computer. The contract was awarded based on a Statement of Work reported in the semiannual SR/AD progress reports for January 1, 1965 – June 30, 1965 (TM 33-243, Vol. I).

A JPL internal document gives the mathematical characterization of the logical operations and the logical elements used to implement them. The Mesa Scientific Corporation completed "Logic Simulation Program Functional Description" on September 23, 1965. The document contains a:

1. Definition of functional characteristics that will be embodied in the logic simulation program.

2. Description of the input, output, and operational characteristics of the program.

3. Description of the methods for using the program including the preparation of input data, the requesting of program operations, and the interpretation of the results.

Mesa's most recent progress report for the work on the computer program (November 1 – November 30, 1965) shows that the detailed flow charting is complete. Keypunching is completed for phases that have been coded. These include logical equations and data checks.

During the next quarter, the program will be completed and actually checked at JPL on an IBM 7094. The abbreviated science data system for an ultraviolet spectrometer will be simulated.

SUPPORT FOR CAPSULE DATA HANDLING SYSTEM

The generation of a time dependent voltage function of the form V/ (at + b) is required by the mass spectrometer. This has been done by an analog method that, at

best, approximates the desired V(t). Furthermore, time compression and expansion is not readily realized. Two approaches to generating the curve digitally are under investigation. One involves the generation of 2^{11} combination of states (PN generation) and a code translation from a nonweighted 11-bit code to a weighted 14-bit code by a diode matrix. The other is the synthesis of a sequential network capable of generating the inverse curve to 14-bit accuracy.

Both approaches involve the simultaneous minimization Boolean functions on an IBM 7094 computer. The program being used is "Boolean Algebra Minimizer" Share Program LLBAM 1197 written in September 1961. As the program stands, it cannot handle the magnitude of the problem in the second approach as is adequate in the first approach only through partitioning. The author of the program will be contacted to determine if it has been improved. If not, the program will be rewritten to take advantage of auxillary storage now available with the IBM 7094. The approach that yields the lower diode count will be found before the end of the fiscal year. See the outline of computer programs below:

COMPUTER PROGRAM I

1. $a_{n-1}\, a_{n-2} \qquad a_{n-11} \qquad Z_1 Z_2 \ldots Z_{14}$

   *Tabulate 2^{11} entries $0 \le n < 2^{11}$

   where $a_n = a_{n-9} \oplus a_{n-1} \oplus W$

   The initial states are:

   $$a_{-1} = 1, \quad a_{-i} = 0 \ \text{ for } \ 0 \le i \le 11$$

   $Z_1\ Z_2 \ldots Z_{14}$ represents binary equivalents of:

   $$V_n = \frac{16.383}{1.7320 \times 10^{-6}\, n + 10^{-3}} \qquad \text{for } 0 \le n < 2^{11}$$

   to 14 place accuracy.

2. Boolean Algebra Minimizer

   a_{n-i} $1 \le i \le 11$ $\qquad$ Z_i $1 \le i \le 14$

   (input) $\qquad$ (output)

   Minimization Criterion
   Minimum Diodes Disjunctive
   (Minterm) form

   *Terminate process when

   $a_{n-i} = 0$ for all i i.e., $n = 2^{11}$

COMPUTER PROGRAM II

1. Tabulate

$$V_n \qquad V_{n+1} \qquad 0 \leq n < 2^{11}$$

$$V_n \neq V_{n+1} \quad \text{except for}$$

one case, i.e., $n = 2^{11} - 1$

$$V_{2^{11}-1} = V_{2^{11}}$$

$$\underbrace{Z_1 Z_2 \cdots Z_{14}}_{V_n} \qquad \underbrace{Z_1' Z_2' \cdots Z_{14}'}_{V_{n+1}}$$

of the 2^{14} entries, 2^{14}, -2^{11} are unused, i.e., forbidden. These combinations should be added to those of Program I and corresponding entries for V_{n+1} are optional (i.e., -).

2. Boolean Algebra Minimizer

$$\underbrace{V_n}_{\text{input}} \qquad \underbrace{V_{n+1}}_{\text{output}}$$

Minimization criterion same as Program I.

CAPSULE DATA HANDLING SYSTEM

NASA Work Unit 186-68-03-04-55
JPL 384-61601-2-3240
D. W. Slaughter

OBJECTIVE

The long-range objective is to develop concepts for the design of the data-acquisition circuits that are required to match the unique and peculiar data characteristics of the scientific instruments to the realizable data-telecommunication system while considering the severe constraints imposed by the capsule engineering limitations, including weight, power consumption, sterilization, shock, and lifetime.

PERSONNEL AND ORGANIZATION

Because of personnel terminations and difficulty in hiring new personnel, this task has been manned at the 0.8 man level from October – December rather than the planned 1.5 man level. However, strenuous efforts were made to rectify the situation during this time. On November 17, the old Science Flight Data Handling Group was split into two groups. One group, under a new supervisor, will handle the Mariner 67 and Mariner 69 project activity; the second group, headed by the supervisor of the original group (Dean W. Slaughter) and called Advanced Science Data Handling, will manage SRT tasks. Two data systems engineers have been hired to report to work on January 17 and January 24. Concerning the immediate problem, Group Supervisor D. W. Slaughter will devote much of his time to this work unit, and Senior Engineer M. Perlman will continue to devote half of his time.

REPORT ON ACTIVITIES

Assistance has been given to other JPL science tasks, especially when this participation contributes to the development of the long-range objective of this work unit, for flight data handling and experiment automation design, logical design, and circuit design. For the Biosatellite Program, NASA Task 189-54-01-04-55, we have performed a logical design for an automated control of the primate urine analysis, the intent being to provide a design that is easily reprogrammable in Earth-based laboratory experiments. The programmer (commercially bought) has the appearance of an old-fashioned drum-like music box. Programming is done by inserting pegs in the desired holes. The work with this experiment has given group engineers a valuable insight into the requirements of biological data automation that may be needed for a capsule or automated biological laboratory (ABL). A proposed design for the automation of data from an x-ray diffractometer (NASA Unit 190-42-03-02-55) has been reviewed and a written report was submitted to the cognizant engineer.

The circuit design for a nonlinear analog-to-digital converter has been completed. The objective is to increase the efficiency in using the low interplanetary communication bit rate by matching the encoding process to the nonlinear characteristic of the scientific instrument. The circuit design will be reported in the JPL SPS and the volume number referenced in a later quarterly report.

Nondestructive readout digital data memories continue to be studied for use in data automation systems for interplanetary spacecraft, capsules, and automated biological laboratory. Application and electrical interface information continues to

be supplied to the engineer responsible for developing these memories, R. H. Nixon (NASA Work Units 186-58-06-07-55 and 125-23-02-14-55). The following problem is being considered: in conventional digital computers, the address that contains data or instructions for the current step in the process also calls out the address of the next step. If any memory address is defective or contains faulty data, the system cannot then proceed properly to the next step, and the sequence of operations is hung up. In a ground system, the faulty equipment is repaired; however, in a spacecraft payload, we are required to provide for automatic self-repair and/or partial success (i. e., data from some of the instruments). Besides reprogramming the equipment by ground command, the following solutions are being considered:

1. Redundant circuits including redundant memory locations.

2. A provision for backup addressing generated externally by a simple binary counter and decoding matrix.

Item 1 would use error-detecting circuitry to detect the presence of an error and would generate an alternate address or sequential routing; item 2 would prevent the memory from hanging up in a step whose loss would be of only minor consequence to the total mission objectives.

The gas chromatograph and the mass spectrometer are instruments that are proposed for a Mars landing capsule, and whose signal output characteristics present difficult problems in data encoding for transmission over a low-rate interplanetary radio link. Figure 1 shows one possible analog output from a gas chromatograph. The location of the peaks on the time-related abscissa, their amplitude, and the areas under the peaks give the information on the molecular constituents of the gas. The peaks vary widely in width; the communication data rate in a sample data system will probably not be enough to catch the narrow peaks. A system has been proposed that will transmit only the essential information; i. e., peak location, peak amplitude, and some measure of area. The proposed design will also handle the problem of superimposed peaks, as shown in Fig. 1, and operates as follows: The analog data is converted to digital samples at enough rate to generate a dozen or more samples across the narrowest peak. Peaks are detected by a digital differential analyzer that, in effect, sets the point where the succeeding sample decreases after an earlier sequence of increasing values. The partly superimposed peak as well as a good measure of the area is obtained by detecting the inflection points on the curve; i. e., the point where the rate of change of values changes slope (second derivative equals zero). Digital circuits set this point by comparing the differences of successive samples. Considering the mass spectrometer data handling problem, all the information resides in the location and amplitude of the peaks; however, a readout of the inflection point on each side of the peaks will enhance confidence in the validity of the data by showing that the peaks are not the result of noise spikes or digital circuit errors. It would be most embarrassing to identify the presence of an element on Mars that later turned out to be nothing more than a glitch in the data system. During the rest of the fiscal year, a detailed logical design will be performed. It is expected that this design will be done in breadboard form using integrated circuits.

NEW WORK PROPOSED FOR REMAINDER OF YEAR

For development of new onboard data handling equipment using some sort of adaptive encoding technique, the performance of any system (breadboarded or computer simulated) must be verified for any and all conceivable unexpected outputs from

the instrument, including unexpectedness in the scientific phenomena, partial failure, or other unexpected performance of the instrument. Because it will be difficult to coordinate tests of various data handler mechanizations with the laboratory operation of a breadboard instrument, we are investigating the acquisition of a tape recorder and data buffer for convenient storage and reproduction of experimental data. The equipment requirements for simulation of instrument data sources is being investigated. It is anticipated that a large part of the procurement funds allotted to this task will be used for getting this equipment, assuming that suitable existing equipment cannot be located at JPL.

A paper titled "On Adaptive Data Control and Processing for Scientific Experiments On-board Planetary Probes" will be presented at the Conference on Adaptive Telemetry sponsored by Goddard Space Flight Center on February 15 – 16. The development of standards for the design of efficient and reliable science data automation equipment for planetary spacecraft will continue to be developed by close contact with experimenter groups.

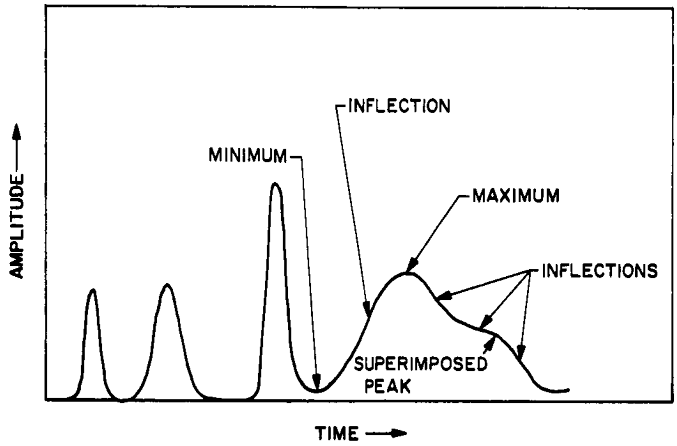


Fig. 1. Simulated analog output for a gas chromatograph

SPACECRAFT DATA PROCESSING

NASA Work Unit 186-68-03-05-55
JPL 384-61701-2-3340

R. F. Trost

OBJECTIVE

The primary objective is to demonstrate the feasibility of an advanced engineering data handling system (EDHS). Feasibility will be demonstrated for: hardware, including reliability, weight, and power costs; and, also, efficiency of information transmission. A secondary objective is to provide meaningful information for later flight system development, design, and fabrication.

INTRODUCTION

In the last quarter of FY 1965, a decision was made to embark on the development of an engineering data compression system and its attendant functions. Data compression is defined as the removal of redundancy from sensor signals. Functions attendant to data compression are confidence sampling, controlled redundancy introduction for operational measurements, data buffering, and priority selection during buffer overloading.

STATUS OF WORK UNIT

The manpower level on this task has recently been reduced from three engineers to one engineer. This reduction occurred prematurely (because of personnel attrition) and, therefore, the current effort is concentrating mostly on data generation and software simulation.

PROGRESS

Figure 1 is an updated version of the development work plan for the EDHS, and summarizes the progress made since July 1965. Note that "Data Generation" is behind schedule, mostly because of the unexpected manpower reduction mentioned. Also, note that the "System Test" has been delayed by one quarter.

Two internal JPL publications have been written that explain the EDHS philosophy in detail. One is essentially a functional specification of the EDHS, and the other is a very detailed explanation of two particular subsystems in the EDHS.

The simulation of one of the EDHS transfer functions on an SDS 930 computer is continuing well and is on schedule. A major problem, however, is the generation of simulated data; solutions to this problem are being studied. One possible solution to the data generation problem is the current development of an IBM 7094 computer program that applies various compression algorithms to actual engineering telemetry data (e.g., Mariner IV). Aside from permitting a data compression study of actual

telemetry data, it will also be used to extract certain channels for input to the simulated EDHS.

FUTURE WORK

The planned activities during January – June are basically a continuation of the simulation and data generation efforts. Technical reports on these efforts will be made available at the proper times.

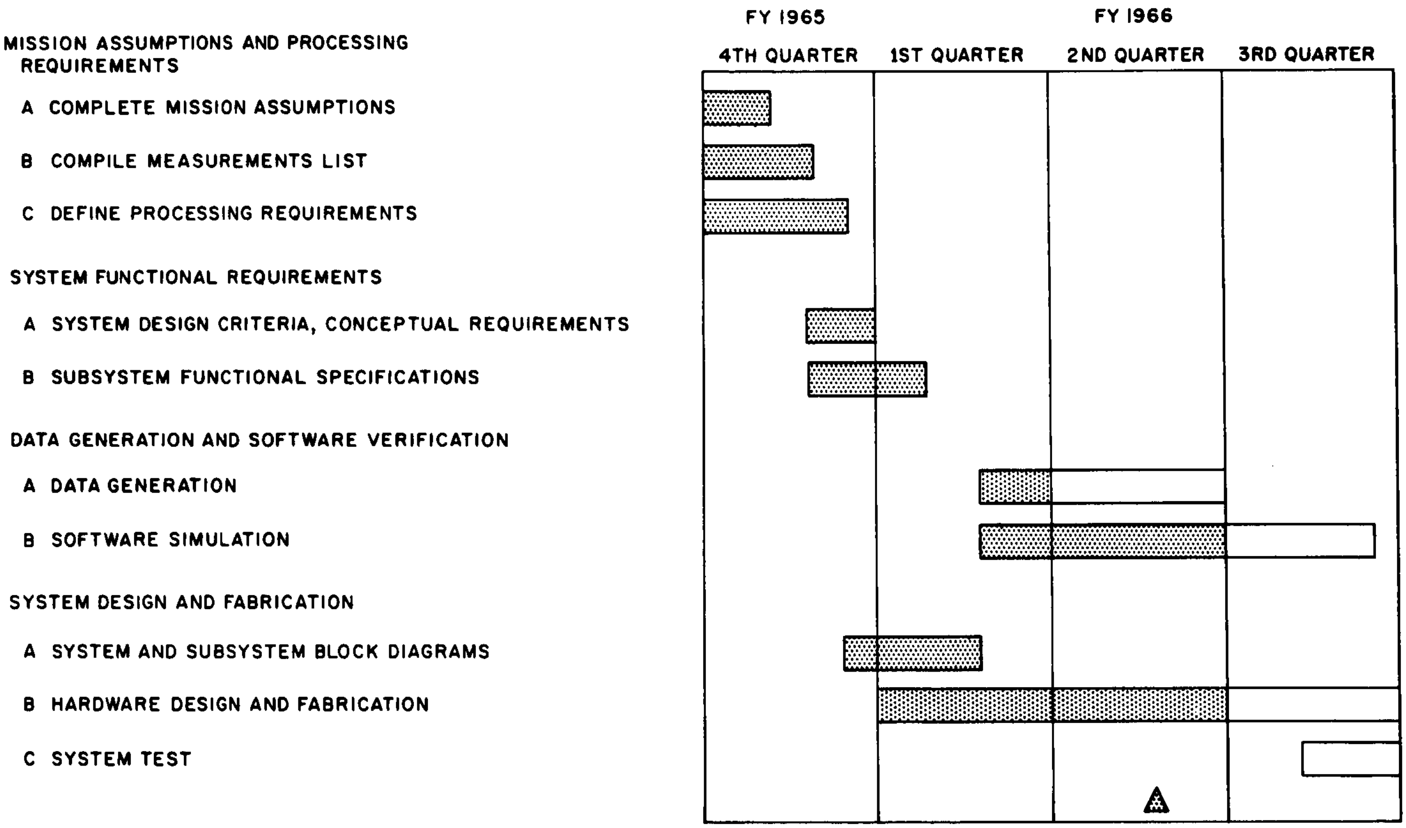


Fig. 1. Current status of development work plan for engineering data processing system (shaded areas represent completed work)

CRITICAL DATA RECORDER TELEMETRY SYSTEM DEVELOPMENT

NASA Work Unit 186-68-04-01-55
JPL 384-66001-X-3340

W. E. Arens

OBJECTIVE

The objective of this task is to develop the telemetry system for the critical data recorder (CDR) which will be capable of providing (1) touchdown diagnostic data in the event that Surveyor telecommunications are lost during a nominal landing and (2) data relative to the nature of the lunar surface in the event of either a nominal landing or a catastrophic landing (velocities in excess of 13 ft/sec but less than 600 ft/sec).

The primary function of the CDR spacecraft telemetry system will be to receive, condition, process, store, and ultimately readout, through appropriate modulated subcarriers, data providing the following information:

1. Order of occurrence of "n" specified potential events.
2. Time elapsed between each of the above "n" events.
3. Fact of occurrence or non-occurrence of "m" specified untimed events.
4. Touchdown acceleration/time profile providing rise time, peak-g level, and profile duration.

REVIEW OF CDR EFFORT

On October 7, 1965, a new CDR team, composed of some members of the previous team and new members from Division 33, met with team leader M. G. Comuntzis. The Mission Objectives, mainly taken from a JPL internal document, outlined a starting point for the CDR task. However, a greater emphasis was placed on Hi-Impact (10, 000 g) design.

The cognizant engineer for Division 33 reviewed the data encoder logic diagram which was the result of previous team efforts, and noted some questionable areas in the design. Discussions followed with other team members as to the real needs of the CDR user. As a result of the discussions, a different approach was taken for data storage and data sampling. The new logic design included a high resolution time-tagging system, a magnetic core memory, and a flexible sample system.

The area of most concern was the type of modulation to be used. The resolution of this question resulted in an extension of the CDR team effort from six to eight weeks. The modulation study did not delay the data encoder logic design effort since the data encoder was designed to be independent of the modulation scheme used.

A Division 33 CDR Design Review was held on November 30, 1965, where the detailed results of the preliminary design study were presented. The following modulation systems were discussed:

1. Direct FSK.
2. PSK-PM.
3. FSK-PM.

The results of the study indicated that the following two systems offered the best performance characteristics in view of defined ground rules and constraints:

1. PSK-PM (48 cps loop BW and 511 bit PN Code).
2. FSK-PM (48 cps loop BW).

Following the design review, the FSK-PM system was selected, primarily for the following reasons:

1. A predetection recording technique using noncoherent detection can be used in addition to coherent real-time detection.
2. PSK-PM possesses a real-time PN acquisition problem which would probably necessitate nonreal-time demodulation of the data.

Following acceptance of the telecommunications system design by Division 33, the following design reviews for the complete CDR package were presented:

1. December 9, 1965 - for representatives from ORAD, *Voyager*, and *Surveyor*.
2. December 16, 1965 - members of Bellcomm representing General Phillip's Office (*Apollo*).
3. December 20, 1965 - for JPL Division Chiefs.

The time required for the preparation of the presentations resulted in a second rescheduling of the CDR task completion date; the eight-week effort was changed to a twelve-week effort. Following the above design reviews the rough drafts of the functional specifications were submitted to JPL's Documentation Group. The specifications were returned to the cognizant engineers for corrections on January 11, 1966, and are presently being reviewed.

SYSTEM DESIGN

1. Block diagram - The block diagram for the data encoder is shown in Fig. 1.

2. Timed Events - There are 16 timed events, each of which can be encoded (if the event occurs) into a ten-bit word; the first five bits identify the event, and the second five bits give the time that has elapsed between the end of the previous event and the start of the new event. The resolution of each timed event is $\geq$ 125 microsec and is dependent on the elapsed time between events.

3. Timed Events Time-Generator - The timed events time-generator is a 22-stage counter with a time range of 0 to 512 sec.

4. Untimed-Event Logic Register - There are 35 untimed events which are temporarily stored (if they occur) in the untimed-event register for 512 sec after the last timed event occurs. At the end of the 512-sec count period, the data is shifted out of the untimed-event register and into a magnetic core memory at a 100-kc rate. After all data is shifted into the memory, the shift register continues to shift zeros into the memory until the memory is filled with the preset number of data bits (225 bits in the preliminary design). The untimed-event register clock is then inhibited by the frame sync pulse.

5. Magnetic Core Memory - The magnetic core memory design is based upon the use of 30-mil isodrive cores and has a potential storage capability of 1000 bits. The data is read in "serially" at at a 100-kc rate, and is read out "serially" at a one-bit-per-second rate. The core format is first-in-first-out with a preset frame capacity (225 bits in the preliminary design). The electronics, associated with the memory, provides the following functions:

    a. Recycles the readout so that the stored data can be repeatedly sent to the transmitter for transmission over each of the seven antennas.

    b. Initiates the frame sync pulse that is used to trigger the untimed-event register clock OFF, the antenna switching logic, the reduced-power mode switch, and the radio power ON switch.

6. Antenna Switching Logic - The antenna switching logic consists of a seven-stage register. The antenna logic is switched on every second frame-sync pulse and sends a 3-v bias to the appropriate antenna switch input.

7. Modulator - The data encoder modulator consists of a rate limiter and a voltage controlled oscillator (VCO).

8. Power Switching - The power switching is accomplished by three DPDT latching type hi-impact relays (data encoder logic relay, radio power relay, and low power mode relay).

9. Accelerometer - The accelerometer is an omnidirectional piezoelectric device that consists of a spherical piezoelectric ceramic shell filled with a quasi-fluid to provide mass loading. The analog output is fed to 8-v-level detectors that trigger eight temporary storage flip-flops in the untimed register and three timed event gates. The acceleration profile is obtained by recording the peak-g level as an untimed event, and recording the rise time and duration of profile by three timed accelerometer events.

For information concerning the telecommunications design details of the CDR, the following references are available:

1. The CDR Function Specifications:

Specification Number	Title
SAA-50532-FNC	Functional Specification, Antenna Subsystem, Critical Data Recorder
SAX-50530-FNC	Functional Specification, Radio Subsystem, Critical Data Recorder
SAR-50529-FNC	Functional Specification, Telecommunications System, Critical Data Recorder
SAN-50531-FNC	Functional Specification, Data Encoder Subsystem, Critical Data Recorder
SAG-50538-FNC	Functional Specification, Ground Support Equipment, Critical Data Recorder

2. Division 33 Weekly Progress Reports, W. R. Arens to M. G. Comuntzis; and a JPL internal report.

FUTURE ACTIVITIES PLANNED

The following activities will be undertaken as available manpower and funding permits.

A. Modulation and Detection (Flight and Ground)

1. Conduct an industry survey for voltage-controlled oscillators.

2. Procure and evaluate selected units.

3. Design, procure required components, breadboard, and evaluate the FSK subcarrier modulation system for the Data Encoder.

4. Design, procure the required components and equipment, fabricate, and evaluate the ground demodulation system for the real time demodulation of the FSK-PM spectrum.

5. Design, procure the required components and equipment, fabricate, and evaluate the ground demodulation system for predetection recording and subsequent detection of the FSK-PM spectrum.

6. Conduct detailed system tests for (4) and (5) to properly evaluate and compare the performance of each detection technique.

B. Accelerometer

1. Conduct an industry survey for omni-directional accelerometers.
2. Procure and evaluate selected units.
3. Procure and evaluate available amplifier designs for the selected accelerometers.
4. Design and evaluate an accelerometer amplifier in-house (if required).
5. Conduct an industry survey for micro-electronic threshold detectors.
6. Procure and evaluate selected micro-electronic threshold detectors.
7. Design, procure required components, breadboard, and evaluate the accelerometer measurement portion of the data encoder.

C. Memory

1. Define requirements and prepare a detailed design specification for the core memory.
2. Award a development contract for the procurement of a prototype core memory.
3. Evaluate the core memory from (2).

D. Logic Circuits

1. Conduct an industry survey for available micro-electronic logic circuits applicable for the data encoder.
2. Procure and evaluate selected units.
3. Investigate custom modifications of commercially available circuits if large advantages could be realized thereby.
4. Request JPL component parts qualification testing for those circuits most adaptable to the data encoder requirements. (If not already qualified or being qualified.)

E. Data Handling

1. Complete the detailed logic and circuit design for the entire data handling system using updated information from items A, B, C, and D.

2. Procure the required components, breadboard, and evaluate the entire data handling system design as defined in (1).

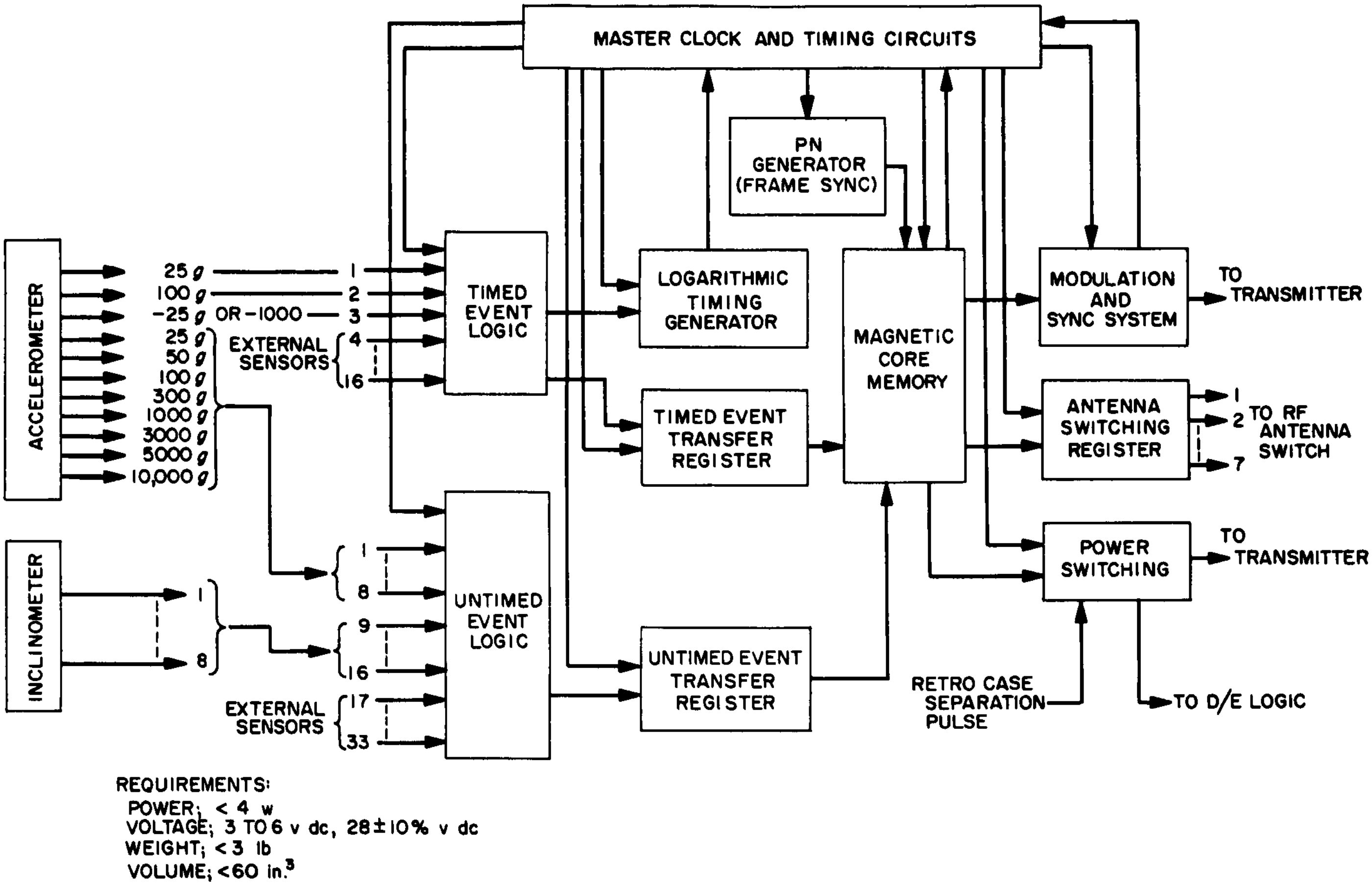


Fig. 1. CDR data encoder block diagram

RADIO FREQUENCY TEST CONSOLE*

NASA Work Unit 186-68-04-03-55
JPL 384-61201-2-3341

F. J. Charles

OBJECTIVE

The radio frequency (RF) test console, when completed, will be used as a precision laboratory tool to assist the evaluation of various telemetry techniques and their interaction with the RF system. The console will be used extensively to support the capsule telemetry relay link and the capsule telemetry low data rate tasks, spacecraft telemetry and video studies, and spacecraft and capsule command modulation systems development.

RADIO FREQUENCY TEST CONSOLE, PHASE I CONTRACT

The RF test console Phase I contract (JPL 950144) was awarded to Westinghouse Corporation, Baltimore, Maryland on March 5, 1964. The primary goal of this contract was to build a precision 50 Mc signal-to-noise mixer and demonstrate experimentally that an RF signal-to-noise ratio could be set and maintained within a tolerance of ±0.3 db for 4 hours. Also, Westinghouse was required to study practical methods of mechanizing an equivalent DSIF transmitter/receiver pair (including possible future capability) with an accuracy and precision of at least an order of magnitude better than that obtainable from an operational DSIF transmitter/receiver pair.

The significant results and the conclusions reached during this contract are summarized in a final report. Also, the detailed experimental and analytical work performed under this contract is available in the form of appendixes to the final report. For convenience, some of the more important results will be reported here.

The main aim of the contract was to determine the accuracy with which average signal-to-noise ratios at 50 Mc could be set. To do this, a matrix of all possible signal-to-noise settings (25×10^4 of them) was arranged into four quadrants and ten settings from each quadrant were selected at random, plus the corner setting. The mean, variance, and standard deviation of each quadrant were calculated. By comparison, each quadrant was a subset of the total matrix population and a mean, variance, and standard deviation were calculated for all the readings. From these calculations a 95% confidence interval with 5% tolerance limits was applied and it was found that no more than 5% of the readings would fall outside of ±0.155 db. Also, as a result of extensive testing, the noise power spectral density at the signal-to-noise mixer output was determined within ±0.05 db by the frequency response of the mixer. A functional block diagram of the RF test console is shown in Fig. 1.

A design review of the contract was held at Westinghouse in Baltimore on March 10, 1965 with ten JPL representatives (selected from Sections 331, 334, 336, and 339) attending. The design review consisted of a presentation of the significant results of the study effort including the proposed methods for building the RF test

*The contract was completely funded in FY 1965 and, therefore, does not appear as a formal task in FY 1966; however, the progress of the RF Test Console will be reported here and in later reviews.

console. Also, a demonstration of the signal-to-noise mixer and the method to verify the spectral uniformity of the noise at the mixer output, using an SDS 910, was presented. There was unanimous agreement among the JPL attendees that both the quality and quantity of the Westinghouse effort was well worth the money spent. The effort under Phase I was completed, including delivery of the final report, in March 1965.

RADIO FREQUENCY TEST CONSOLE, PHASE II CONTRACT

A second contract (JPL 951140) was awarded to Westinghouse on June 29, 1965 to complete the fabrication of the RF test console in accordance with the revised specification in the final report of contract 950144. The major effort to date on this contract has been directed mainly towards the development of circuits commonly used throughout the console. The physical completion of the RF test console is estimated to be 20% finished. Completion of this task is scheduled for the end of the first quarter of FY 1967.

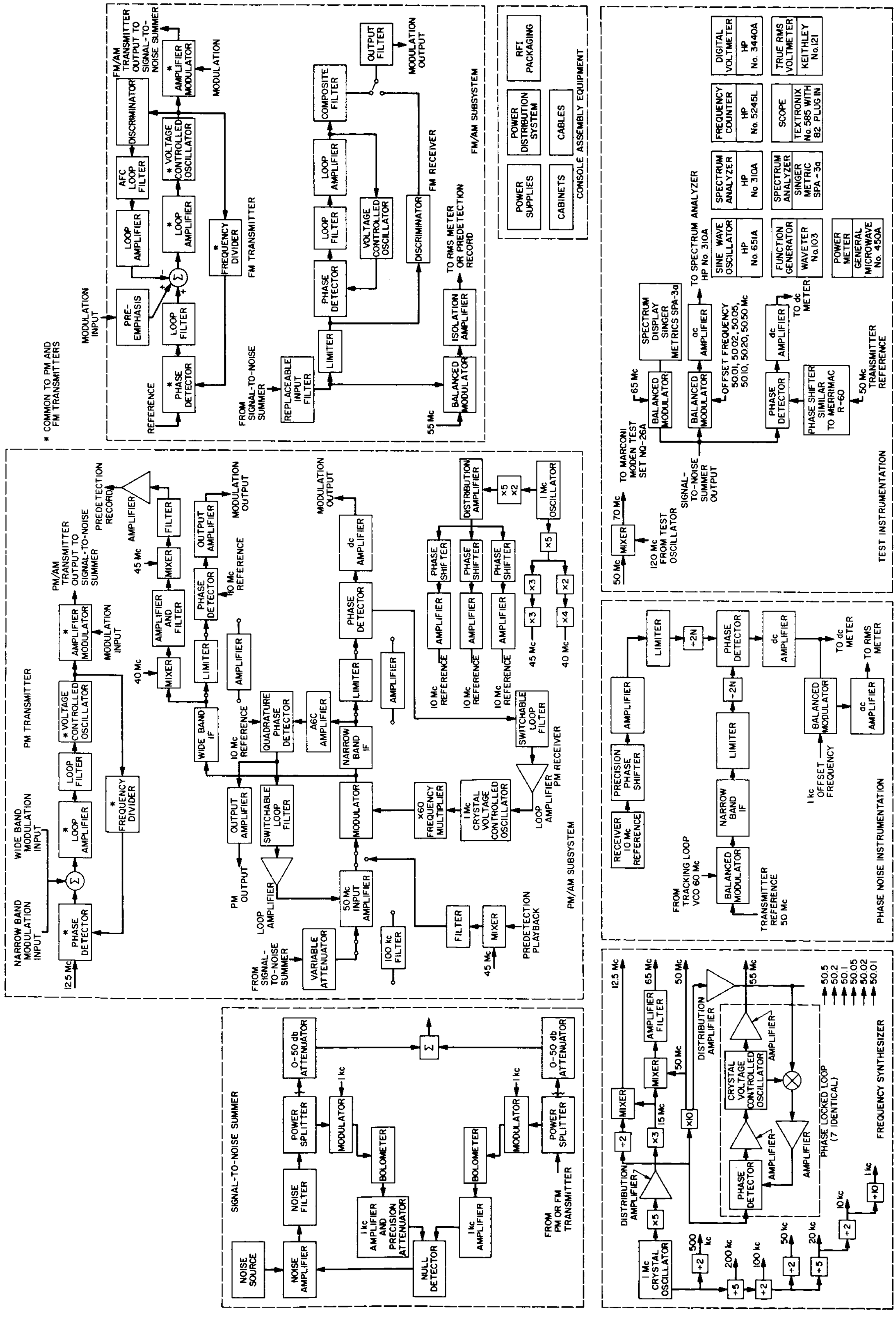


Fig. 1. Functional block diagram for RF test console

CAPSULE RELAY MODULATION SYSTEMS DEVELOPMENT

NASA Work Unit 186-68-04-04-55
JPL 384-61301-2-3340
J. C. Springett

OBJECTIVE

This task is intended to develop modulation, synchronization, and coding techniques applicable to the transmission of data from a landed planetary capsule to an orbiting or flyby parent spacecraft at a bit-rate range of 10 to 200, 000 bits/sec. Both feed-through and full demodulation/detection systems will be studied with emphasis on communication efficiency and reliability.

Studies and experimentation are being made on: (1) double sideband and single sideband PM and FM modulation, (2) problems associated with acquisition, (3) methods of bit and word synchronization, (4) effects of nonlinear elements (limiters, etc.) used in the process of demodulation/detection and remodulation of the spacecraft RF carrier, and (5) threshold criteria.

THEORETICAL MODULATION STUDIES

Most of the theoretical work during the first half of the fiscal year has been calculating the power spectra of single sideband phase modulation (SSB/PM). The form of the modulated signal expressed in complex analytic form is given by

$$\underline{S}(t) = \exp\left\{\alpha\left[X(t) + j\hat{X}(t)\right]\right\}\exp(j\omega_0 t) \tag{1}$$

Where X(t) may be any lowpass periodic or aperiodic function possessing no singularities on $-\infty<t<\infty$, $\hat{X}(t)$ is its Hilbert transform, ω_0 is the carrier frequency, and α is a constant.

To obtain the power spectrum of $\underline{S}(t)$ it is necessary to evaluate the second-moment function of the modulating process, $X(t) + j\hat{X}(t)$. In an actual system, the modulation will be of such a form (e.g., binary) that the calculation of its second moment function is impractical, if not impossible. As a result, we have resorted to a class of gaussian modulating signals with identical spectral characteristics as those of the actual modulation. Here, the complex second-moment function, $M_S(\tau)$, has been shown to be

$$M_S(\tau) = \frac{1}{2}\exp(-j\omega_0\tau)\exp\left\{2\alpha^2\left[R_X(\tau) - j\hat{R}_X(\tau)\right]\right\} \tag{2}$$

where $R_X(\tau)$ is the autocorrection function of X(t), and $\hat{R}_X(\tau)$ is its Hilbert transform.

To evaluate the power spectrum it is necessary to Fourier transform $M_S(\tau)$ using a computer for a given $R_X(\tau)$. This phase of the work was started late in the second quarter of FY 1966. The first autocorrelation function chosen was

$$R_X(\tau) = \frac{\sin \tau}{\tau} \tag{3}$$

because of its unit (one-sided) spectral width. Spectral calculations are being made for carrier to total power ratios ranging between - 0.5 - 10.0 db to obtain the modulated carrier spectral width relative to that of the modulation. A comparison is also being made with the more common double sideband phase modulation.

A report containing the full analysis as well as plots of typical spectra is in preparation. Portions of this report will be submitted to the JPL SPS, Vol. IV, for publication.

EXPERIMENTAL MODULATION STUDIES

An experimental SSB/PM modulator has been constructed and tested for a pseudo random binary modulating signal. The Hilbert transform of a typical "bit" in the binary sequence is shown in Fig. 1. For the first experiments, a linear approximation to the Hilbert transform (as shown by the dotted lines in Fig. 1) was made. A 10 kc carrier was used with the phase modulator being constructed with a phase-locked loop and the amplitude modulator with chopper switches. The lower sideband, as expected, was suppressed but not completely eliminated. Spectrum plots were made for various modulation indicies (θ_m = 0, 1/4, 1/2, 3/4, and 1 rad peak); a typical plot is shown in Fig. 2. The plots showed that the amount of lower sideband suppression was greatest for low modulation indicies. As a result, it will be necessary to make higher order fits to the Hilbert transform if sufficient lower sideband suppression is to be effected for high modulation indicies.

The modulated waveform was also fed into a limiter to remove the amplitude modulation, and spectrum plots showed that the normal double sideband phase modulation spectrum was recovered. Demodulation is then performed by a coherent phase detector.

A report detailing the results of these first investigations will be available in the third quarter. Further work will be extended to higher classes of modulation, and to measuring signal-to-noise performance.

NOISE PERFORMANCE ANALYSIS

A JPL internal report was published on July 15, 1965, and the highlights were submitted for publication in JPL SPS 37-36, Vol. IV.

A study to determine the output noise distribution density in the first zone of a filter-limiter combination was completed. Distribution density plots for input signal-to-noise ratio's of $-\infty$, - 30, -20, -10, 0, + 10, + 20, and + 30 db were obtained, as well as plots of the output of a filter following the limiter where the ratios of filter bandwidth to limiter bandwidth were 3/4, 1/2, 1/4, and 1/10, and the input signal-to-noise ratio was - 20 db. The results showed that the output noise of the limiter first zone was near gaussian only when the input signal-to-noise ratio was + 30 db or above. Further, the output of the filter following the limiter had a near gaussian output only when the bandwidth ratio was 1/10 or less. All results have been documented in a JPL internal document.

Future analytical work will take the results of the SSB/PM spectrum analysis and determine the second-moment function at the output of the limiter for a SSB/PM input.

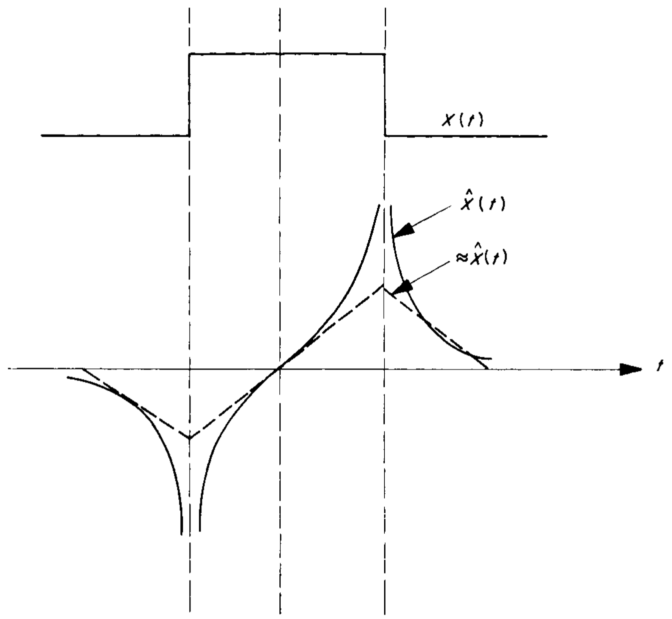


Fig. 1. Hilbert transform

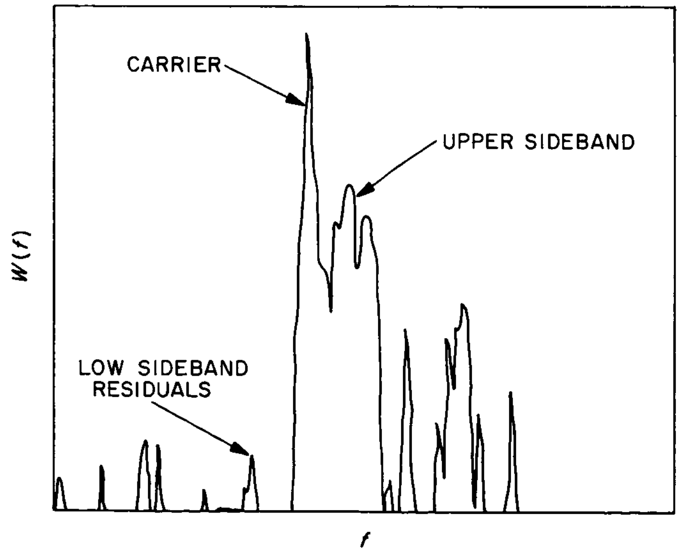


Fig. 2. Linear approximation to $\hat{X}(t)$, single sideband phase modulation

CAPSULE ANTENNA STUDY

NASA Work Unit 186-68-04-06-55
JPL 384-61501-2-3360

J. F. Boreham

OBJECTIVE

The objective of this task is to study the problems of high-impact survival as applied to S-band low-gain antennas and to develop a series of prototypes that reach the specified results. This task is closely coordinated with, and heavily supported by, the High-Impact Communications Subsystems task, 180-68-04-14-55.

STATUS SUMMARY

The high-impact survival antenna problem has been approached from the basis that a low-gain antenna with good circular pattern symmetry, with high front-to-back ratio (backlobe suppression), with a 3 db beamwidth in the 70 to 100 deg region, and with good axial ratio within the 3 db points, must be developed to survive 10, 000 g. Therefore, three different types of antennas are now under study.

The first of these is a cupped turnstile antenna similar to that used in that Mariner IV high-gain antenna feed. As a point of departure, an actual flight type element was shocked in progressively increasing steps to find its failure point. This was found to be between 3000 and 6000 g. A post-6000-g tested element is shown in Fig. 1. From here a ruggedized version was designed and has been successfully shocked to 9000 g. However, at this level, the wall of the open ended square cavity (cup) deformed slightly (0. 015 in.). The post-9000-g shock tested cupped turnstile may be seen in Fig. 2. This antenna has survived 18 high-impact shocks in the 5000- to 9000-g level. A redesign was started to add stiffness to the cup walls. This includes enlarging the rib around the cup mouth and adding a similar rib part way down the side. This part is in fabrication and tests will be resumed on the square cup design early in the 3rd quarter. Also in fabrication are a set of cylindrical cups. Not only will these cylindrical cups be inherently more rugged, but they will also produce better wide angle pattern symmetry.

This turnstile uses a short circuited half wavelength balun to drive the turnstile elements. An alternate arrangement is to use an open circuited quarter wavelength balun, which eliminates the top part of the support column above the plane of the turnstile elements (Fig. 1). A parametric study has shown that the required beam shape can be produced with the turnstile element completely recessed below the mouth of the cup. This has two obvious advantages because it reduces the depth of the antenna and gives better protection for the critical components. A first cut at this design change has been made and the quarter wavelength balun turnstile is in fabrication. Future developmental areas involve (1) a test to find the power capacity of the two designs, and (2) to produce a high-impact surviving radome to keep foreign matter out of the critical areas and to close off the open mouth of the cup.

The second type of antenna under study is a cavity backed planar spiral. This is the most compact of the types under investigation, with a diameter of 0.6λ and a depth of only 0.2λ. Its ultimate weight should be under 0.4 lb, however, this will depend on the cavity stiffness needed to keep the feed point from fracturing. This

feed point must be kept small for electrical considerations and, therefore, the cavity and circuit board containing the spiral must be inherently stiff. Impact tests of a commercial model showed survival at 4000 g, but catastrophic failure (broken feed point) at 5600 g.

Electrically the VSWR is less than 1.6:1 from 1.9 to 2.4 Gc and is fairly insensitive to objects in its near field. Pattern tests run at 2.3 Gc showed good symmetry and little squint (about 1 deg). Because the cavity of the failed commercial unit showed a permanent deformation, a unit was built using an extremely rugged cavity with a modified feed point and the same circuit board design. This antenna survived 8000 g but failed at 10,000 g. As a result (electrically), the pattern showed several degrees of squint (shift of the pattern axis of symmetry from the physical axis) and a higher VSWR over the band. The antenna was again rebuilt with a repaired feedpoint and with a 1/32-in.-thick epoxy fiberglass board bonded to the circuit board to increase the diaphram stiffness (Fig. 3). This antenna failed on its only test at 10,000 g, when the bonded board delaminated around the feed point and the feed point refractured (Fig. 4). This development is delayed while waiting for new circuit boards to be fabricated. A thorough retest of the pattern characteristics of another commercial antenna of the same type has shown that this type antenna has an inherent squint problem. The boresight shift ranges 1 to 7 deg with the minimum at 2.3 Gc. Therefore, it appears that a design problem exists here.

The third type antenna under investigation is a sidewall radiating waveguide ring antenna (Fig. 5). This antenna is inherently the most rugged and the least vulnerable to damage. However, to generate a circularly polarized broadside beam, the two orthogonally located inputs must be fed with equal power in phase quadrature. Therefore, a power splitter (probably just a coaxial tee) and a phasing section (a quarter wavelength longer feed line) must be designed, incorporated, and tested with the antenna. Present thinking is to feed the antenna from the inside and to locate the power splitter and phasing section in the cylindrical hole in the center of the antenna. Main characteristics of the antenna are 3 db beamwidth of 70 deg and a narrow-band impedance characteristic (VSWR $< 2{:}1$ at 2.30 Gc $\pm$ 30 Mc). High impact tests of the antenna will start early in the 3rd quarter.

An out-of-house contract, which was planned to be let in the 2nd quarter, has been delayed because it originally was to be concerned only with the development and study of high-impact surviving, low-gain S-band antennas; however, because the problem of developing a 10,000-g surviving antenna does not appear as difficult as originally thought, a reevaluation of the scope of the contract is in process.

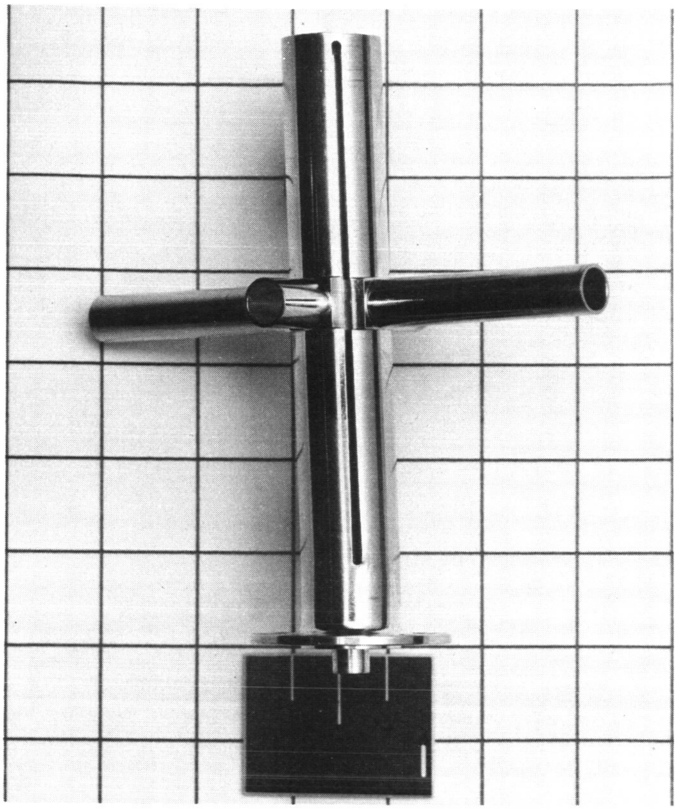


Fig. 1. *Mariner IV* high-gain feed element after 6000-g impact test

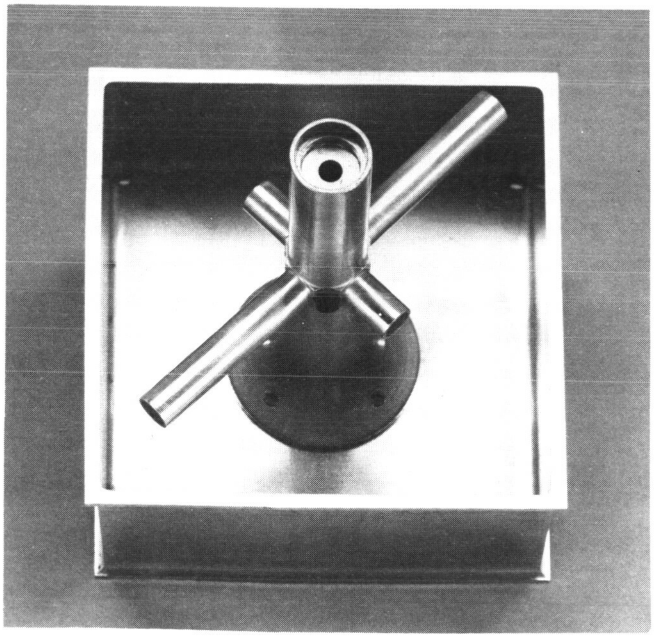


Fig. 2. Post-9000-g shock tested cupped turnstile

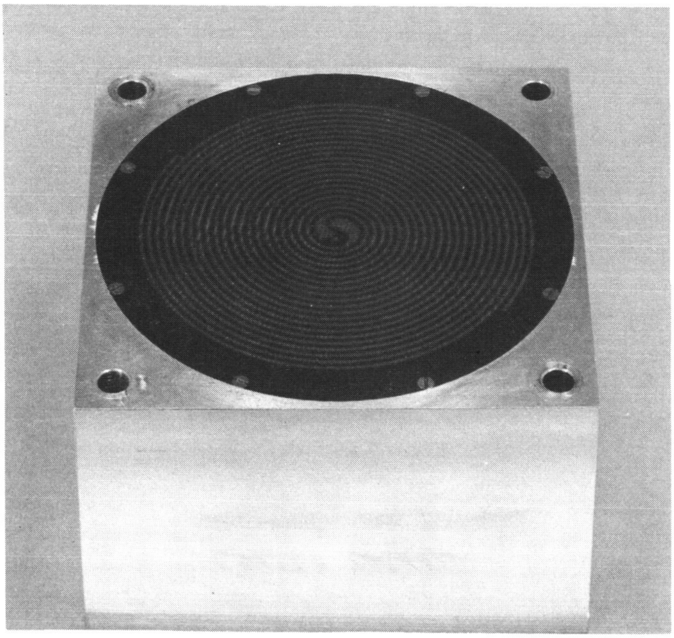


Fig. 3. Cavity backed spiral with extremely rugged cavity

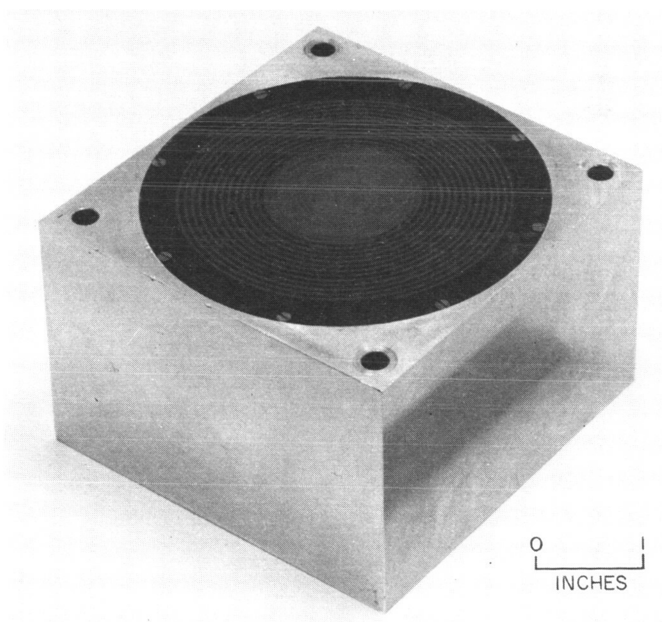


Fig. 4. 10,000-g failed cavity backed spiral

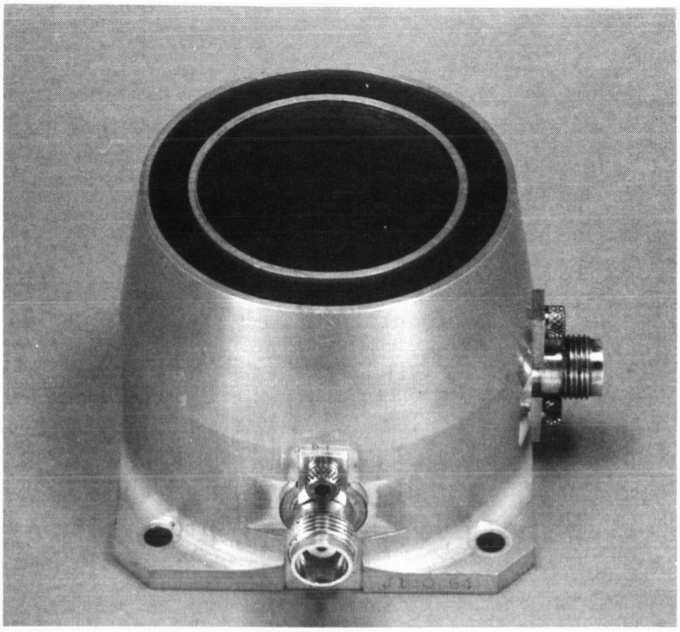


Fig. 5. Ruggedized side wall radiating waveguide ring antenna

CAPSULE RF RELAY

NASA Work Unit 186-68-04-08-55
JPL 384-63101-2-3360
W. L. Tisdale

OBJECTIVE

The objective is to perform the analysis and engineering needed to develop a prototype UHF transmitter and to develop an automatic acquisition system for a phase lock loop receiver for a capsule-to-bus RF relay system. The transmitter will be a lightweight UHF unit that will survive a high-impact landing on a planetary surface and operate in that environment.

CAPSULE TRANSMITTER

The transmitter is being developed in-house taking advantage of much of the design of the S-band transmitter developed under Low Data-Rate Telemetry RF System Development (150-22-05-17-55). Since the last reporting period it has been decided to divert most of the receiver development effort and develop a 400 Mc transmitter. The relay transmitter will consist of the VHF portion of the S-band unit (191-Mc, 20 w-point) retuned for 200 Mc, followed by a varactor doubler. It is expected to furnish 15 w at 400 Mc, and to survive a 10,000-g shock. An engineering model of the transmitter without the final doubler has successfully passed the 10,000-g shock test and the -10 to +75°C temperature test. The design of the final doubler is 75% complete. The transmitter will be ready for the prototype contract stage at the end of FY 1966. The high-impact work is heavily supported by 186-68-04-14-55, High Impact Communication Subsystem Technology.

SPACECRAFT RECEIVER

The actual mechanization of the acquisition system is done by building automatic sweep and trigger circuitry into a 200 Mc breadboard receiver. This receiver was developed during FY 1965, when the most likely relay frequency appeared to be 200 Mc and is largely composed of <u>Mariner C</u> transponder circuitry. This receiver is used to gather the data for the acquisition study.

It is the intent of this work unit to fully develop the acquisition circuitry. To produce a 400 Mc receiver would then require only a new RF amplifier and local oscillator multiplier chain.

ACQUISITION STUDY

The acquisition study is directed to provide parametric information applicable to a wide variety of capsule missions. Analytical and empirical methods are used to determine the relations among parameters including sweep rate, acquisition probability, signal-to-noise ratio, frequency offset, and loop bandwidth. The 200 Mc breadboard receiver is used to gather the empirical data and to verify predicted relationships. The rough draft of the acquisition report, part I (no sweep shutoff), is complete. The experimental determinations of acquisition probability are consistent with results of the General Electric study reported in IRE, SET-8; September 1962, No. 3 p. 210. Preliminary indications are that sweep time can be increased by at least a factor of two if a trigger-sweep shutoff is used.

RF POWER AMPLIFIERS

NASA Work Unit 186-68-04-09-55
JPL 384-63401-2-3360
L. J. Derr

OBJECTIVE

This effort is a continuation of the FY 1965 effort as presented to NASA headquarters on October 15, 1964, and modified at JPL on September 27, 1965. The objectives are (1) the development of S-Band RF power amplifiers for approved, spaceflight missions, (2) to increase the available RF power levels consistent with projected spacecraft needs and capabilities (now estimated to be 20 to 500 w for the Voyager and advanced planetary programs), (3) to improve the efficiency, stability, reliability, and operating life of RF power amplifiers, and (4) to develop efficient heat dissipation techniques for RF power amplifiers.

ESFA DEVELOPMENT

The purpose of this contract JPL 951105 is to develop variable power (20 to 100 w and 100 to 500 w) RF amplifiers using a hybrid RF circuit design, electrostatic focusing, and a radiation cooled collector system. The contract is divided into four parts:

1. Development of a 20- to 100-w tube.
2. Production of five 20- to 100-w tubes for life test.
3. Development of one 100- to 500-w tube.
4. Production of five 100- to 500-w tubes for life test.

Item 1 was funded from carry-over FY 1964 OTDA (311-03-53-52) and the contract was signed with Eitel McCullough May 10, 1965. The specific tube being developed uses helical-resonator buncher cavities and a double gap output cavity.

The electrostatic focusing system, the buncher cavities, and the output cavity are designed and fabricated for the first experimental tube. This tube will use a water-cooled collector and an existing electron gun, and is scheduled to be tested in January 1966. The radiation-cooled collector system is being designed and tested separately. Evaporation tests have been completed on the chosen high temperature materials.

Item 3 (100- to 500-w development) will start in FY 1966 from NASA 186-68-04-15-55 money ($100,000, enough for only partial funding) if enough progress is made in Item 1.

HIGH EFFICIENCY TRAVELING-WAVE TUBE DEVELOPMENT

This development seeks an advancement in the present state-of-the-art efficiency (38 to 40%) in traveling-wave tube designs. The goals are 55% at 100 w and 50% at 50 w and the tubes will be conduction-cooled and magnetically focused. The contract will be divided into four parts:

1. Development of a 100-w tube.

2. Production of five 100-w tubes for life test.

3. Development of one 50-w tube.

4. Production of five 50-w tubes for life test.

Because it is easier to scale a tube down in power rather than up, the 100-w development will be started first. It is desired that the 50-w design require only slight modifications to the 100-w design.

Nine vendors were asked to bid. The proposals from the three replying vendors were evaluated, a selection memo was published, and negotiations are scheduled for January 6, 1966, with the chosen vendor, the Watkins Johnson Company. Present funding (this work unit $140,000 from FY 1965 and $40,000 from FY 1966) only covers Item 1.

TUBE EVALUATION PROGRAM

The evaluation of commercial amplifiers serves two main purposes:

1. To advance our knowledge, therefore improving our capability both for in-house development and in directing the outside development contracts now underway.

2. To find out each amplifier's applicability to future NASA programs.

The RF evaluation of Litton's 20-w ESFK and a Hughes 20/5-w traveling-wave tube is 80% complete. These tubes will be environmentally tested (for shock, vibration, and thermal-vacuum) in early 1966. Raytheon will start production of three 22-amplitrons and power supplies in January 1966. The lifetime and reproducibility of the amplitrons are the major interests in this evaluation.

ADVANCED SPACECRAFT TELECOMMUNICATION SYSTEMS

NASA Work Unit 186-68-04-11-55
JPL 384-63201-2-3360
C. E. Gilchriest

OBJECTIVE

The objectives of this work unit are to provide the telecommunication system analysis and synthesis for advanced spacecraft missions and to coordinate the SR/AD work units that relate to the development of the system elements such as transmitters, receivers, modulators, demodulators, encoders, and decoders.

ACTIVITIES

Reliability

The reliability effort has made significant progress in the advancement of both the philosophy and technology of telecommunication system reliability assessment. Review of the results show the continued need for investigation at the present depth and scope. The review also shows specific avenues of activity that should be pursued.

The reliability study contract with Tam Research Associates ended during this period. This procurement covered an assortment of tasks associated with this topic: e.g., system longevity studies, a dormancy study, and system synthesis investigations. Procurement problems have arisen that have caused a discontinuity in the performance of the task. Contractual negotiations are now being made for 18 mo at a labor cost of $36,000.

If the techniques developed in this program are carried out, they will advance the methodology for evaluation of system reliability. The methodology has, however, received less than optimum acceptance and the validity of reliability estimates has been questioned. This lack of confidence has lead to contingent studies of the uncertainty or variability of reliability predictions. The prediction variation studies will evaluate the degree of risk or the confidence interval related to specific reliability estimates. It is intended that this will give a more objective and more quantified comparison among various system configurations.

Continued development of the system reliability assessment methodology will show, in measurable terms, the complete economic costs (manpower, money, weight, power consumption, etc.) of any system change. The following steps shall be taken to satisfy this objective.

1. Study component failure rates and their variability. This makes the assumption that the failure rate of a particular lot of components can be found out to a small confidence interval (because of a high part times hour test), but that later measurements of different lots (say manufactured at a different date) could be found out to the same confidence interval but resulting in far different values from the previous value than would be expected statistically from the sample population. This produces the concept of probability on the failure rate parameter. The objective of this particular aspect of the task would be to assign a realistic

probability density function to the failure rate parameter. Data is not readily available and will require further effort; however, examples can be assumed (such as flat, triangular, gaussian, etc.) for study.

2. Using the concept and functional transformation just mentioned, find out the probability density function of the probability of failure with a given design (the mean value of this probability density function is the usual value given for the probability of failure). Many examples have been worked out.

3. Evaluate several methods thought to yield reliability improvement such as redundancy, dormancy, system synthesis, simplification, parts up-grading, etc. With the probability density function of the probability of failure method, these improvement schemes show that there are usually distinct probabilities of actually causing a system degradation as opposed to accepting the improvement shown by the mean values of these probability density functions (hypothesis testing).

4. The necessary mathematical tools shall be developed for measuring the significance of improvement produced by a proposed system modification. The results, when examined for economics, will lead to best system reliability within the constraints of specific programs. As an example, consider a system having less than adequate reliability. One hypothetical modification requires the removal of a particular part. It is understood that removal of this part would not change the operating characteristics of the system. Because all parts have a failure rate, no matter how infinitesimal, this modification will improve system reliability absolutely; i.e., $P_i = 1.0$. A second modification uses redundancy to get higher reliability. Assume the probability of improvement for this configuration is 0.8. The second modification would produce a greater quantitative system improvement with a higher contingent risk that the improvement could be achieved. Generally, removing a part from a system is less expensive than adding a part, so this modification would also bear the economic consideration of being more expensive.

It is intended that these tools shall be used to support the results obtained from the direct system reliability analysis.

Attempts to incorporate the above results into a reasonable method of allocating the economic factors have been made; but much work remains to be done.

Two internal reports have been prepared: (1) Supplementary Report to a Study on the Uncertainty of Reliability Predictions, and (2) Preliminary Spacecraft Subsystem Dormancy Study. A more comprehensive report is to be prepared on the continuation contract with Man K. Tam Associates.

Surveyor Critical Data Recorder (CDR)

The objective of this task is to conduct a preliminary design of a telecommunications system suitable for a high-impact device that would telemeter critical data from the Surveyor Spacecraft either in a nominal landing or in the event of a failure.

The study proceeded in:

1. Defining the objectives in detail.
2. Outlining the constraints.
3. Finding the functional requirements.
4. Performing tradeoff studies for various modulation schemes, antenna switching, and acquisition problems.

At completion, study recommendations were presented at a division design review.

Signal-to-Noise Ratio Estimator (SNORE)

The long range objective of this task is to develop methods and hardware suitable for monitoring the signal-to-noise ratio of the carrier, subcarrier, synchronization channels, etc. for all projects that might interface with the DSIF. A secondary objective is to make these methods as adaptable as possible so that new interface equipment is not needed with each new project and modulation method.

A design now exists that is entirely dependent on the Mariner C demodulation, and has largely been proven with qualification tests and 8 wk of tracking on the Mariner IV mission. While the operation has not been satisfactory, modifications should be made to incorporate self-calibration means and to extend the range of operation. Also, further analysis should be done to find the:

1. Effect of DIS quantization on accuracy.
2. Effect of offset voltages on accuracy in the various amplifiers.
3. Effect of mismatch on accuracy of the scale factors in the parallel matched filters.
4. Effect of line noise on accuracy.
5. Effect of maximum scale of the A-D converter of the DIS on accuracy.
6. Effect of computer processing on accuracy.
7. Effect of automatic gain control loop filtering on the carrier channel accuracy.
8. Effect of droop on accuracy in matched filter hold circuits.

The SNORE has proven to be a useful tool in verifying station automatic gain control calibration techniques. Consideration should be given to implementing a modification of SNORE in each station because this problem is universal to all projects.

Because the current SNORE design is dependent on the Mariner C demodulator design, alternate methods should be considered to adapt the SNORE principles to other projects using the DSIF such as:

1. Apollo.
2. Surveyor.
3. Lunar Orbiter.
4. Pioneer.
5. Voyager.

These designs have rather diverse modulation-demodulation techniques, all of which can be considered to be "volatile designs." Other means must be considered that will not require redevelopment of hardware. A possible alternate might be to consider more direct computer processing such as some of the spectral analysis techniques used in the Venus radar experiments and now proposed for low bit-rate telemetry.

I. Work Completed

1. Refinement of Basic SNORE Analysis. The exact probability density function for the output of the SNORE was calculated and several important statistical averages were found (TM 3361-65-7).

2. Effect of Holding Circuit Leakage on SNORE Performance. An analysis of the effect on droop on the measurement accuracy of the SNORE was made. A useful by-product of the analysis was the introduction and justification of a figure of merit for measuring SNORE error (TM 3361-65-9).

3. Alternate Means of Estimating Signal to Noise Ratio. An alternate means of estimating the signal to noise ratio of a stationary gaussian process in stationary gaussian noise was developed and analyzed. It was not very practical for telemetry problems, because it required an off-on process (TM 3361-65-8).

4. Effect of Integration Mismatch on SNORE Performance. The practical realization of the SNORE requires parallel integrators. If the gains of those integrators are not identical, there will be a measurement error. An expression for this error has been derived and presented in graphical form (TM 3361-65-11).

5. Effect of Automatic Gain Control Loop Filtering on SNORE Performance. The effect of automatic gain control loop filtering on the signal to noise ratio in the carrier channel (dynamic automatic gain control output) of the SNORE has been found. This has been done by restricting consideration to large signal to noise ratio and using a linear incremental model. Numerical values for the difference between the signal to noise ratio in the automatic gain control output and the carrier signal to noise ratio without filtering are given (TM 3361-65-11).

II. Work In Progress

Work is proceeding smoothly on all problems outlined in the task and no significant problems have been met.

Besides the basic method outlined by Gilchriest (SPS 37-27, Vol. IV), several alternate measurement methods have been considered. Some of these with tentative conclusions include:

1. The method mentioned in 3 above.

2. Curve Fitting Techniques. It is assumed that the forms of the noise and signal spectral are known and it is desired to measure their heights. Using a simple two point fitting technique this method was found to be prohibitively sensitive to small errors in the assumed form of the spectra. It will be considered further.

3. Spectrum Measurement. The measurement of the signal to noise ratio by first estimating the power density spectra for signal plus noise present and for noise alone present and then integrating over frequency to obtain power was considered. The method applies to the same situations as those in 1 above, but it needs much more processing and is, therefore, considered to be inferior to 1.

4. Maximum Likelihood Techniques. The maximum likelihood techniques used to great advantage by Lincoln Laboratory were investigated. It was found that the mathematical details were insurmountable except for simple cases that are already well understood.

5. Extreme Statistics. The possibility of inferring the signal to noise ratio from estimates of the probability of bit error found by using extreme statistics was considered. The method applies to the same situations as the basic method, but gives inferior performance.

6. Digital Implementation. A digital implementation of the present system is being considered.

III. List of Publications

1. "Calculation of the Probability Density Function of the Estimate Made by the SNORE," TM 3361-65-7.

2. "Effect of Holding Circuit Leakage on Measurement Accuracy of the SNORE," TM 3361-65-9.

3. "Signal-to-Noise Ratio Estimation," TM 3361-65-8.

4. "The Effect of Integrator Mismatch on the Measurement Accuracy of the SNORE," TM 3361-65-11.

5. "Effect of AGC Loop Filtering on SNR Measurement in the SNORE," TM 3361-65-12.

Analysis of Cascaded, Frequency-Multiplexed PM Communication Channels

This system is composed of a series of frequency-multiplexed PM communication channels by video-limiting turnaround channels. Angle modulated sine wave subcarriers or binary-valued signals may phase modulate the transmitter of each PM communication channel. Extractors for the information corrected by these signals may process the output of any receiver following the point at which these signals are introduced. The objective of this task is to simplify the problem of evaluating this system to that of evaluating the performance of the extractor in obtaining the information from the desired signal, distortion, and white gaussian noise.

The objective will be carried out by (1) demonstrating that over the frequency band of interest the power spectral density of the gaussian noise at the receiver output is the same as that of the gaussian noise at the receiver input, (2) deriving equations for the amplitudes of the signal x signal intermodulation products of the receiver input and output, and (3) obtaining an upper bound on the power spectral density of the signal x noise component of the receiver input and output. One of the signal x signal components of the receiver output will be the desired subcarrier signal. The remaining signal x signal components and the signal x noise component of the receiver output are distortion.

During the reporting period, an extensive revision of this analysis has been completed. Several corrections have been made and a number of improvements, which will improve and simplify the analysis, have been incorporated.

An error made in the previous analysis has been corrected. It was incorrectly assumed that the receiver of each PM communication channel tracks the average phase of the received signal. The receiver tracks the phase of the carrier component of the received signal. Sometimes the average phase and the phase of the carrier component of the received signal are not the same.

The derivation of the upper bound for the power spectral density of the signal x noise component of the receiver input, the receiver output, and the video limiter output has been improved, resulting in appreciably stronger bounds that are now always applicable. The revised analysis has been simplified by eliminating

derivation of exact expressions for the power spectral density of the signal x noise components of the receiver input, the receiver output, and the video limiter output. These equations could not be evaluated numerically and were only included earlier as a step in obtaining the upper bound.

The analysis has also been simplified by eliminating the analysis for a ∂-law limiter for which a large part but not all the earlier analysis was valid.

Degradation of a PCM Telemetry Channel by Sinusoidal Interference

The objective of this analysis is to find the amount the ratio of the received signal energy per bit to the noise spectral density in a binary communication channel using antipodal signals must be increased to compensate for the degradation caused by the presence of a sinusoidal interfering signal.

Exact expressions for the bit error probability in both the presence and absence of the interference can be derived. The degradation $\delta\lambda_b$ is the factor by which the ratio of the received signal energy per bit to the noise spectral density, λ_b, must be increased to reduce the error probability in the presence of the interference, to that which would exist in the absence of the interference.

The mathematical analysis needed for this task has been completed.

The numerical computation needed to evaluate the mathematical expressions requires evaluation of a numerical integral and solution of an integral equation. The required computer program has been coded and is being checked out. The program now appears to operate correctly. Problems with the iterative procedure used to solve the integral equation have been corrected. It appears that the problem resulted from an inflection point in the function being evaluated and an alternative iterative procedure was developed to correct this problem. Some minor changes to the plotting portion of this computer program must be finished before this problem is completed.

HIGH-IMPACT COMMUNICATION SUBSYSTEM TECHNOLOGY

NASA Work Unit 186-68-04-14-55
JPL 384-62801-2-3550

J. L. Adams
M. G. Comuntzis

OBJECTIVE

To develop the technology necessary to allow the building of communications equipment capable of surviving high impacts (10, 000 g, 500 ft/sec ΔV) with typical spacecraft development constraints (tight schedules, extreme reliability requirements, low production). This work unit will be closely coordinated with the high-impact packaging technology unit. Past developments in conjunction with lunar capsules and in the JPL high-impact program have proven that communication equipment can be made extremely rugged with little sacrifice of other qualities. This effort is intended to provide knowledge concerning the ruggedization of equipment. This knowledge can be used either as design data for hard landers or to allow tradeoffs between ruggedization and retardation systems for the best design of any lunar or planetary lander. This knowledge is essential for the proper design of future Mars landers.

PROGRESS

During this report period, the first module of the three module 3-w, S-band solid-state, high-impact resistant transmitter being developed in cooperation with the JPL Telecommunications Division, successfully survived impacts of 10, 000 g from 200 ft/sec in all principal directions. This module contains the oscillator, two stages of amplification, a doubler, and a tripler. Figures 1 and 2 show the two sides of the module. The second module had earlier survived 10, 000-g impacts in all principal directions. The third module will be a strip-line device and should be extremely impact resistant, because it is a solid device.

The first module contained a JPL high impact crystal. These crystals are being developed under JPL Contract 951080 with the Valpey-Fisher Company. The contract was let on January 25, 1965, and is scheduled for completion about March 1, 1966. During this report period, sealing and mounting problems occurred and were solved. Several prototype crystals have successfully survived high-impact tests. However, delivered items are not yet consistent enough to allow the production of the planned 60 test items. Although individual crystals have performed within specification, others have been rejected for various reasons. No crystals have satisfactorily met phase stability requirements during vibration.

A Hughes Model 216-H Traveling Wave Tube was impact tested to find failure modes and levels. This is not a ruggedized tube. The stock tube degraded when impacted axially and failed after an axial impact of 1000 g from 50 ft/sec.

A ruggedized turnstile omnidirectional antenna was developed and tested. The antenna weighs 3-1/2 oz and has withstood impacts of 10, 000 g from 200 ft/sec in all principal directions with negligible mechanical or electrical damage. Figure 3 shows this antenna. An off-the-shelf Sanders cavity-backed S-band spiral antenna was tested and failed at 5000 g. A ruggedized version of this antenna was developed and has successfully survived impacts of 9000 g from 180 ft/sec. A universal connector

developed by the Telecommunications Division for use with 3/8-in. OD semi-rigid coax successfully survived impacts of 10, 000 g from 200 ft/sec. Omnispectra connectors mounted on orbital space mission coaxial cables also survived 10, 000 g from 200 ft/sec. One solder joint was cracked at the connector-coaxial interface, but electrical performance was not degraded.

Work done in this work unit during this report period is mentioned in SPS 37-35, Volume IV, JPL TR 32-844, "The JPL High Impact Program — 1965," by J. L. Adams and M. G. Comuntzis, delivered at the 35th Annual Shock and Vibration Symposium at New Orleans on October 27, 1965.

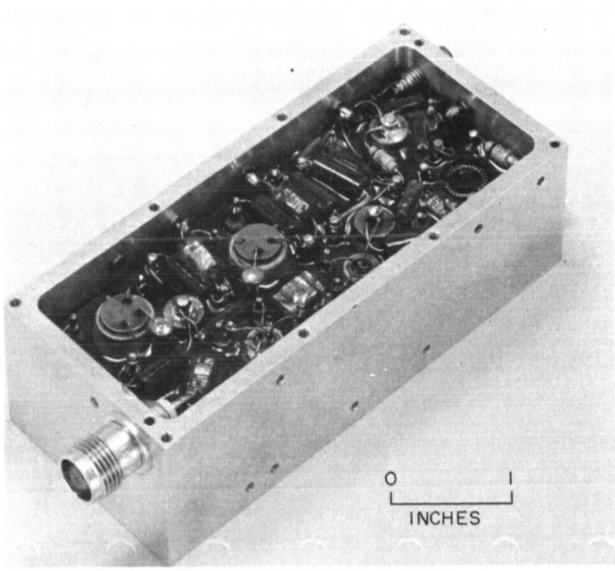


Fig. 1. Modal 1 ruggedized S-band transmitter

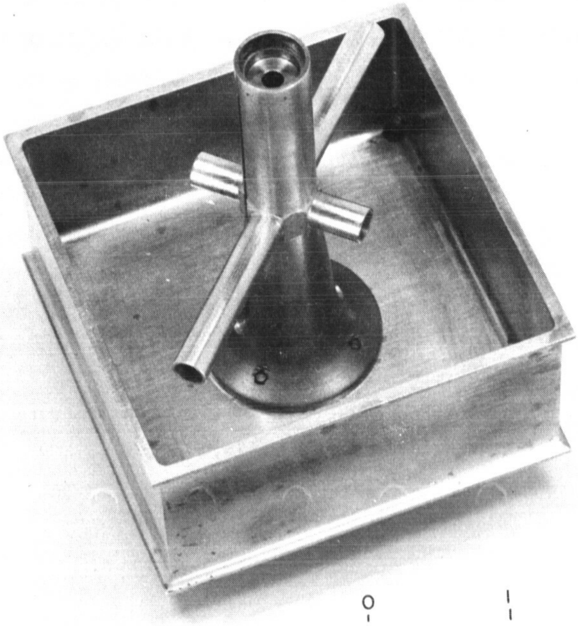


Fig. 3. Ruggedized S-band turnstile antenna

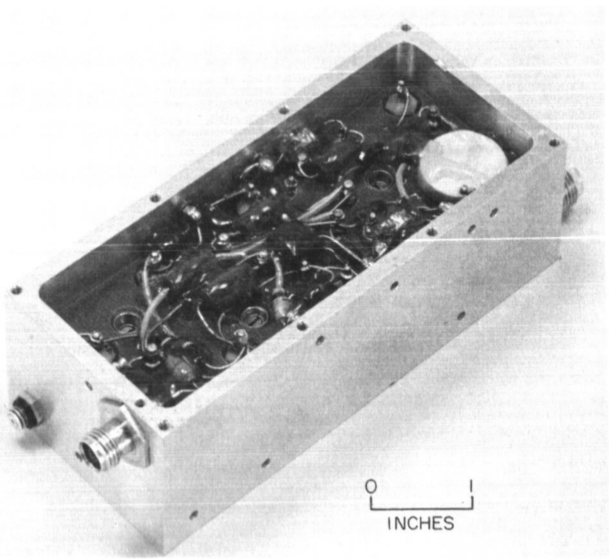


Fig. 2. Modal 1 ruggedized S-band transmitter

100- TO 500-W ELECTROSTATICALLY FOCUSED AMPLIFIER PHASE I

NASA Work Unit 186-68-04-15-55
JPL 384-66301-2-3360
L. J. Derr

OBJECTIVE

The objective of this work unit is to start development of an S-Band (variable power) 100- to 500-w electrostatically focused amplifier (ESFA) using a hybrid design and a heat radiating collector.

STATUS

The funds for this development have been committed. The development at Eimac will begin during the next reporting period when enough progress has been made on development of the 20- to 100-w ESFA supported under RF power amplifiers, 186-68-04-09-55, 384-63401-2-3360.

HIGH-IMPACT SCIENTIFIC INSTRUMENT TECHNOLOGY

NASA Work Unit 186-68-06-01-55
JPL 384-65501-2-3550

J. L. Adams
M. G. Comuntzis

OBJECTIVE

To develop the technology needed to allow the building of high-impact (10, 000 g, 500 ft/sec ΔV) resistant scientific instruments. This knowledge is needed for proper design of any lunar or planetary lander (such as future Mars landers). If the lander is a "hard" lander, the knowledge is design information. If the lander is a "soft" lander, the knowledge is needed to make tradeoffs between equipment ruggedness and retardation system.

PROGRESS

Figures 1 and 2 show the ruggedized gas chromatograph in its present form. Figure 1 shows one of the electronic boards before coating. Figure 2 shows the plumbing inside the instrument. The instrument has not yet been impacted as a unit. Preimpact functional testing is now underway. Figures 3, 4, and 5 show exploded views of the sample valve, an ionization detector, and the pressure regulator. These devices were all developed specifically to survive the high-impact environment. They are applicable to many different scientific instruments besides interest as mechanisms. The sample valve is a three-position rotary gas valve used to interconnect the sample source, the carrier gas, the vacuum line from the jet pump, the sample loop, and the analysis line in various combinations. The valve is powered by regulated carrier gas that is, in turn, controled by a solenoid weighing 8 oz. The ionization detector incorporates adjustable electrodes and the most support to all critical elements. The pressure regulator regulates the 3000 psi carrier gas supply to 65 psi. It is a two-stage device with an adjustment in the low pressure stage and weighs 5 oz.

Work done in this work unit during this report period is mentioned in SPS 37-35, Volume IV, JPL TR 32-844, "The JPL High Impact Program – 1965, " by J. L. Adams, and in a paper "High Impact Spacecraft Equipment, " by J. L. Adams and M. G. Comuntzis, delivered at the 35th Annual Shock and Vibration Symposium at New Orleans on October 27, 1965.

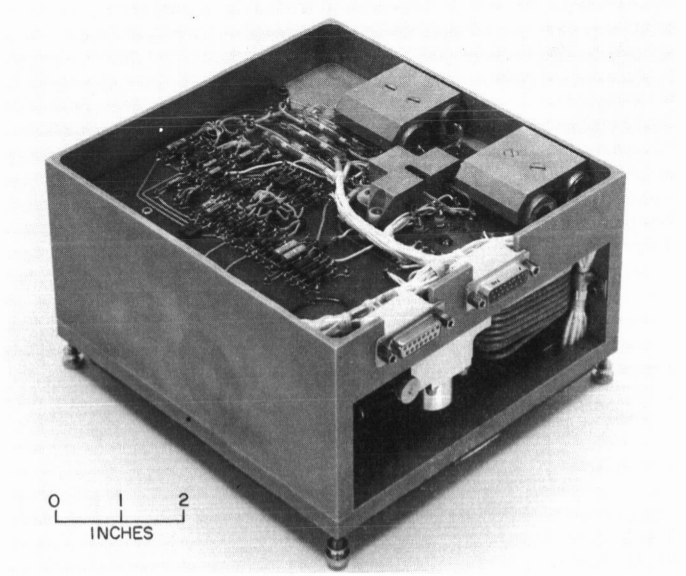


Fig. 1. Ruggedized gas chromatograph

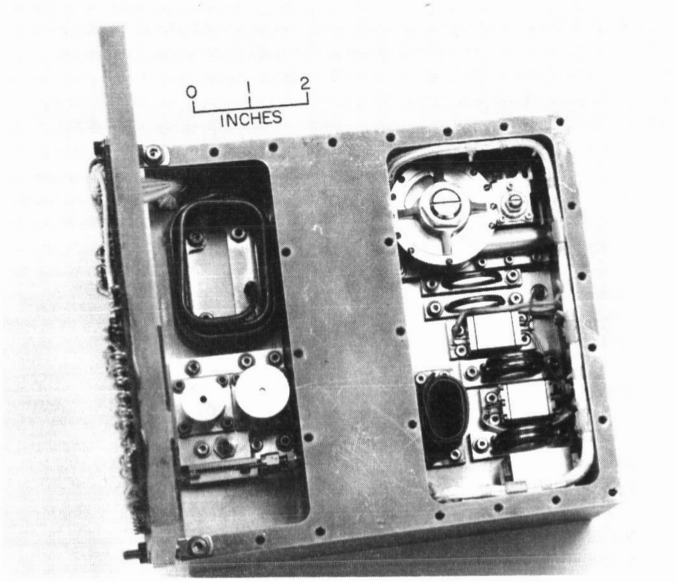


Fig. 2. Interior of ruggedized gas chromatograph

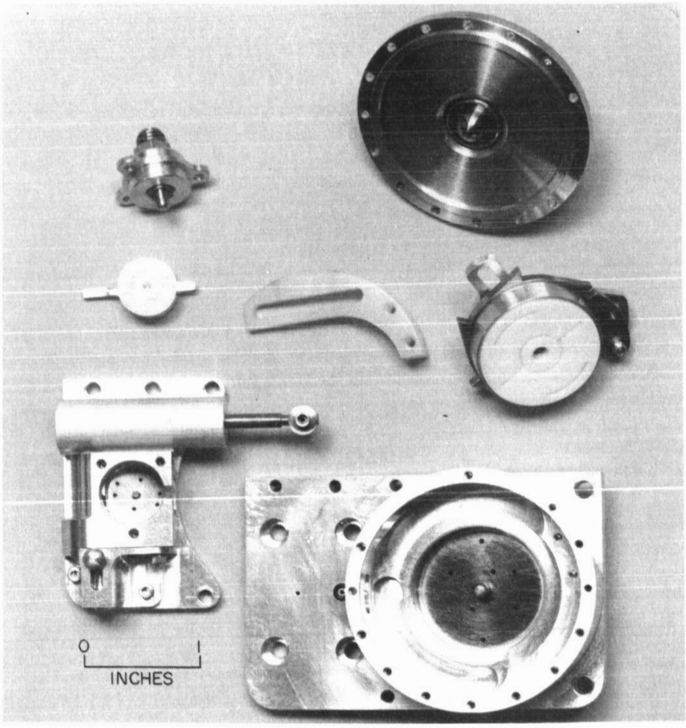


Fig. 3. Gas chromatograph sample valve

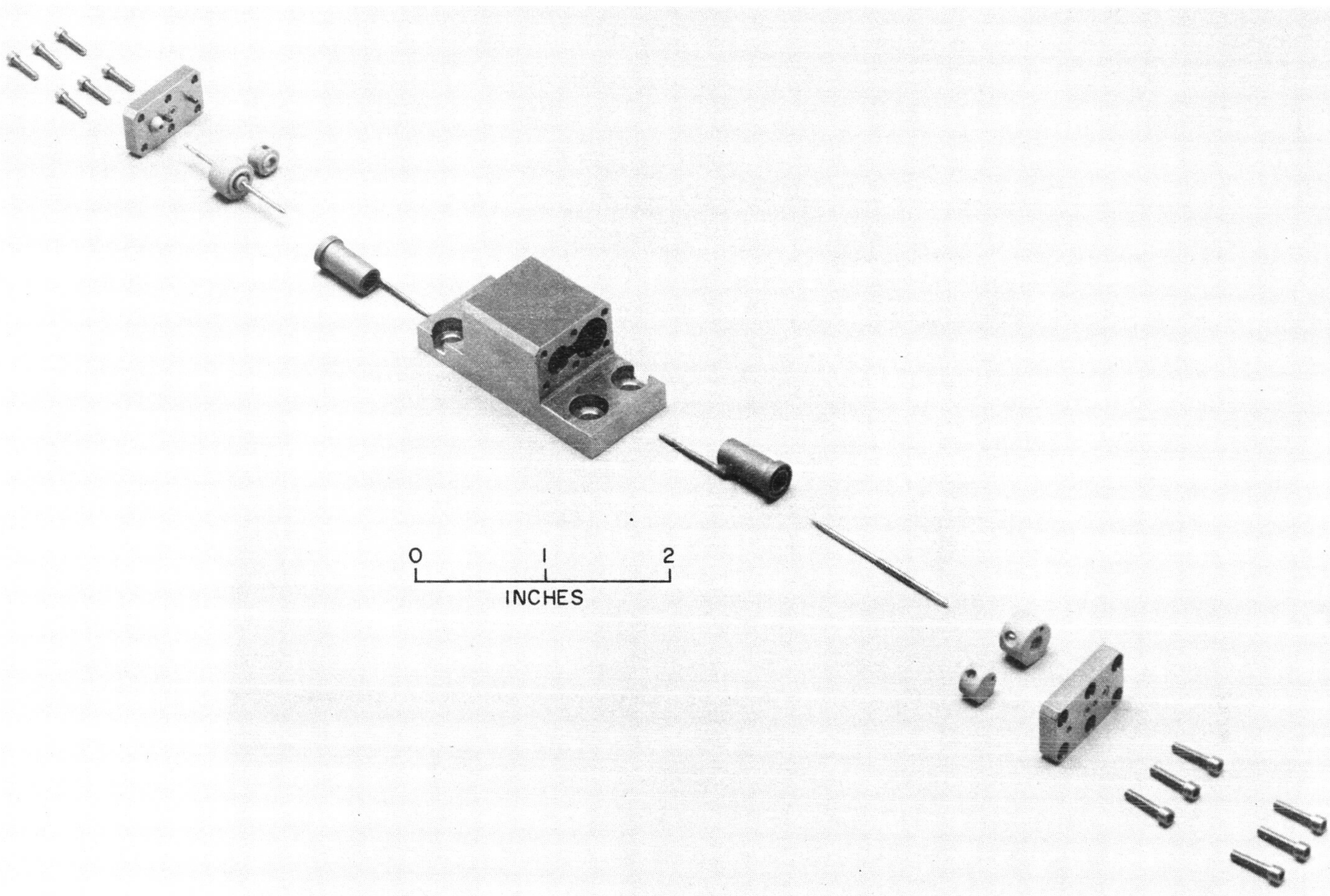


Fig. 4. Ionization detector

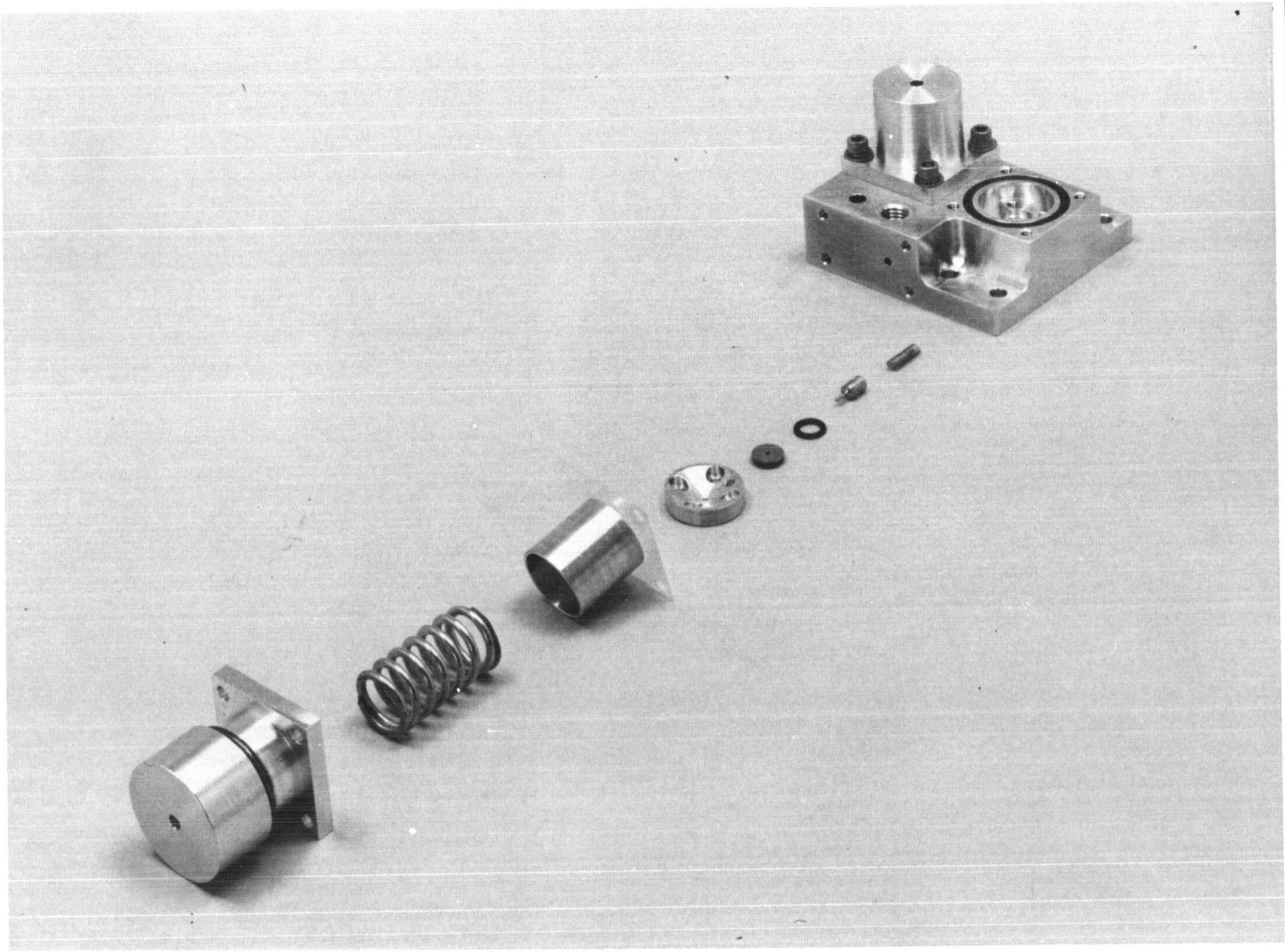


Fig. 5. Ruggedized pressure regulator

HIGH-IMPACT BATTERY TECHNOLOGY

NASA Work Unit 186-68-07-01-55
JPL 384-64301-2-3550

J. L. Adams
M. G. Comuntzis

OBJECTIVE

To develop the technology needed to build batteries capable of surviving high-impacts (10, 000 g, 500 ft/sec ΔV) with typical spacecraft development constraints (tight schedules, extreme reliability requirements, low production). Past developments in conjunction with lunar capsules and in the JPL high-impact program have shown that batteries can be made extremely rugged with little sacrifice of other qualities. This effort is intended to provide knowledge concerning the ruggedization of batteries. This knowledge can be used either as design data for hard landers or to allow tradeoffs between ruggedization and retardation systems for the best design of any lunar or planetary lander. This knowledge is essential for the proper design of future Mars landers.

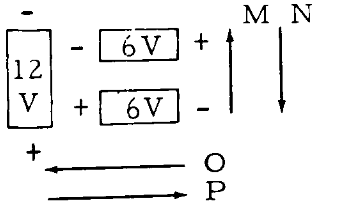
PROGRESS

Table 1 lists battery impact tests made during this report period. Figure 1 explains the impact directions referred to in Table 1. The cells were always completely supported in a rigid (typically 3/8-in. wall aluminum) fixture. The small 6-cell battery (ESB 225-1000, 20 whr) failed because of plate buckling and later grid and lead damage. Figure 2 shows typical plates from this battery after the final 7200-g shock. The Yardney HR-1 silver-zinc cells survived impacts of 10, 000 g in all directions with no detectable short-term electrical degradations. The cases cracked and the plates deformed slightly, but charge-discharge curves showed no detectable effects caused by the impacts. The Gould nickel-cadmium button cells all survived the impact testing with no observable degradation. However, voltages were intermittent during certain impacts. This was because the cell plates are held in contact with the case by springs. When the cells are impacted so the acceleration is toward the spring, the plate mass collapses the spring and breaks the electrical contact.

Development of prototype battery cases made of Union Carbide Polysulphone is underway between Divisions 34 and 35. These cases should have the necessary strength and elongation properties to avoid case cracking at impact. When they become available, prototype cells will be manufactured and tested. Sterilizable materials will be included in these cells whenever possible.

Additional write-ups on this work unit can be found in SPS 37-35, Volume IV, JPL Technical Report 32-844, "The JPL High Impact Program — 1965, " by J. L. Adams, and in a paper "High Impact Spacecraft Equipment" by J. L. Adams and M. G. Comuntzis, delivered at the 35th Annual Shock and Vibration Symposium at New Orleans on October 27, 1965.

Table 1. Battery impact tests

Battery	Condition	Potting	Direction	g level	ΔV, ft/sec	Comments
Whittaker P.S.D CD-3 sealed silver cadmium cells 2 potted in fixtures	Charged	Epon 815	A	9, 800	176	Potting and case cracked No internal damage
Plates in bag potted in structure	Charged	Epon 815	Edgewise	11, 600	135	Battery was destroyed
ESB 6-cell battery	Charged	Epon 815	C	5, 000	107	Survived
ESB 6-cell battery	Charged	Epon 815	D	5, 000	107	Survived
ESB 6-cell battery	Charged	Epon 815	B	5, 000	108	Survived
ESB 6-cell battery	Charged	Epon 815	C	8, 000	115	Survived
ESB 6-cell battery	Charged	Epon 815	D	7, 200	117	Failed
Yardney HR-1 2 cells potted in a fixture	Charged	Solithane 8	A	8, 000	122	
	Charged	Solithane 8	A	6, 300	122	
	Charged	Solithane 8	C	6, 920	148	Survived
	Charged	Solithane 8	B	6, 910	148	Case cracked. Vacuum potting sucked out some KOH.
	Charged	Solithane 8	B	9, 000	166	
	Charged	Solithane 8	C	9, 000	179	
	Charged	Solithane 8	D	10, 000	167	
	Charged	Solithane 8	A	12, 000	171	
Gould nickel-cadmium button cells	Charged	828/D	M	5, 800	106	
	Charged	828/D	M	5, 900	109	
	Charged	828/D	P	5, 900	109	Survived
	Charged	828/D	N	5, 600	108	Intermittants when impacted axially with acceleration in the positive (+) direction
	Charged	828/D	O	5, 600	109	
	Charged	828/D	M	8, 000	165	
	Charged	828/D	N	8, 000	168	
	Charged	828/D	O	8, 000	167	
	Charged	828/D	P	8, 500	170	
Impacted under load 12v-500BH-40Ω 6V-100B-75Ω						

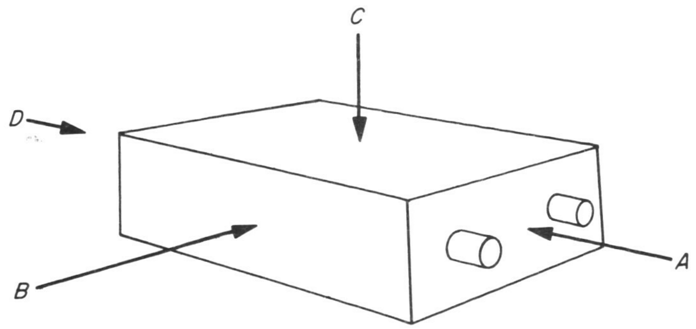


Fig. 1. Battery impact acceleration directions

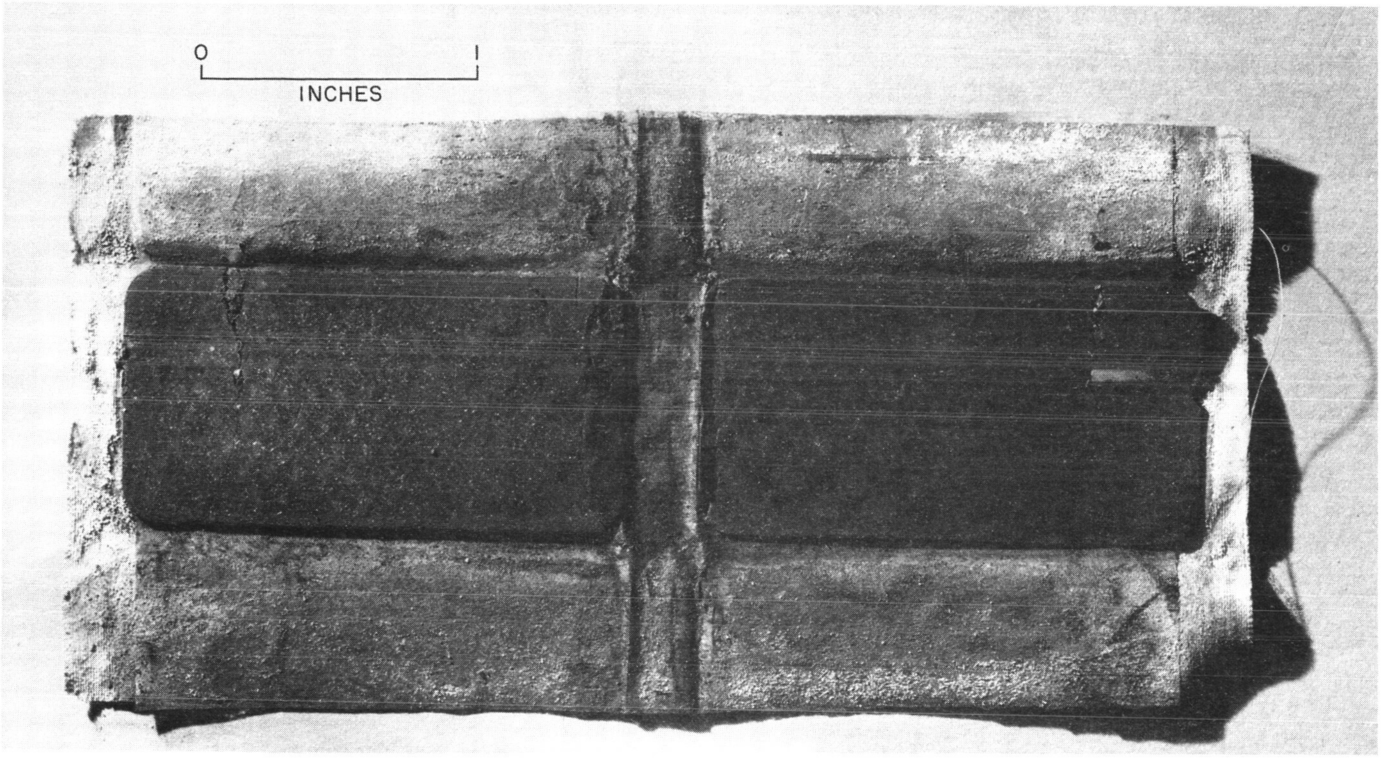


Fig. 2. Battery plates after impact

TOUCHDOWN STABILITY STUDY

NASA Work Unit 186-68-09-03-55
JPL 384-63501-2-3500

J. A. Garba

OBJECTIVES

The objectives of this NASA work unit are to conduct a three-dimensional stability study of a three-legged vehicle, and to set stability boundaries for the *Surveyor* spacecraft as a function of 11 parameters. Nine of these parameters define the initial conditions (velocities and attitude) of the *Surveyor* at touchdown as prescribed by the flight control system; the remaining two are the lunar slope and the coefficient of friction.

The effect of a soft surface on the landing dynamics of a three-legged spacecraft is now being planned to be included in a followon effort.

COMPUTER PROGRAM DESCRIPTION

JPL Contract No. 951304 for $73, 690 (FY 1965 Task 187-06-12-06-55) was issued to the Bendix Corporation, Bendix Products Aerospace Division, South Bend, Indiana, on July 1, 1965. The contractor was selected based on the technical completeness of the proposed work and the extensive experience with a similar analysis performed on the lunar excursion module.

The current contract covers Phases I and II of the study. Phase I consists of the development and checkout of a digital computer program for the analysis of a three-legged spacecraft landing on a hard lunar surface. Phase II will entail the use of the computer program to define stability boundaries for the *Surveyor* spacecraft.

PHASE I

The contractor has completed the development of the computer program and the analysis of five check cases supplied by JPL. A JPL support role in checkout of the program was examination of the results of these five check cases. In evaluating the validity of these results, time-motion and time-force histories as well as rates of energy dissipation during the landing period were examined. Based on these considerations, the results were found to be favorable.

On November 30, 1965, the Bendix Corporation made an oral presentation to the JPL cognizant technical personnel outlining completed work and tentative plans for future studies in Phase II. An informal progress report, "Interim Report on Surveyor Lunar Touchdown Stability Study," Bendix Aerospace Division Report No. MM-65-16 was presented to JPL then.

JPL found that the present program, while giving satisfactory results, requires some improvement aimed mainly at reducing machine time. JPL considers this improvement especially desirable because the final version of this computer program will be used at JPL for *Surveyor* and other future projects after the conclusion of the present contract. In line with this goal, the current version of the contractor's digital computer program has been successfully compiled and executed on the JPL computer.

To date, considerable progress has been made on Phase I; however, several initial nonconservative estimates, such as (1) manpower required to complete Phase I; and (2) machine time per landing case have resulted in a cost and schedule overrun.

On December 9, 1965, the Bendix Corporation was asked by JPL to explore several program modifications that will reduce the present machine time by an estimated factor of two. Until these improvements are made, the Phase I effort is considered to be "conditionally successful."

The present projected overrun for the Phase I effort including the current program improvements is $15, 000. The initiation of any Phase II effort is contingent on the successful completion of Phase I.

PHASE II

To limit the number of cases to be investigated in Phase II, and to help the contractor in making the selection for the most critical cases for the *Surveyor* spacecraft, JPL has investigated the general spacecraft landing problem. Results of this investigation are summarized in a JPL internal document Report on the stability of multi-legged entry vehicles during soft landings.

A firm plan for Phase II has not now been approved by JPL.

PHASE III

FY 1966 funds will be used for an extension into the study of soft surface effects on lunar touchdown. Because the Manned Spacecraft Center (MSC) at Houston, Texas has expressed interest in this work, effort and resources will be pooled by MSC and JPL.

A first draft of a statement of work in three parts for Phase III has been prepared and sent to MSC for comment. Part 1 requires the investigation of three different soil types characterized by their failure modes using the full size *Surveyor* footpad. Part 2 requires the establishment of analytical models of the soft surface for the three types of soils. Part 3 requires the writing of a subroutine to handle surface-spacecraft interactions that is compatible with the Phase I digital computer program.

On completion of a final statement of work for Phase III, a Request for Quotation will be sent to Bendix on a single source basis.

ENGINEERING MECHANICS STUDIES

NASA Work Unit 186-68-09-04-55
JPL 384-62301-2-3500
J. E. Long

OBJECTIVE

Studies performed under this work unit are:

1. To identify new requirements and develop concepts which may provide substantial improvements in a spacecraft performance.

2. To assess the activity within the division to enhance the success of future missions.

3. To support Advanced Technical Studies.

For FY 1966 specific objectives are to develop understanding of "unique" impact attenuators, nonaxisymmetric loading of capsule structures, impact attenuator removal mechanisms, and heat shield-ablation product interactions to insure that appropriate approaches are utilized on *Voyager*.

IMPACT ATTENUATION

Evaluation of impact attenuation methods other than by crushing material (i.e., balsa wood) has begun. This evaluation will provide background on potential alternatives to the present proposed *Voyager* design. Present effort will concentrate on the "practical" consideration of utilizing pneumatic impact attenuators. Such considerations are:

1. Method of attachment of payload to attenuator.

2. Premature rupture protection.

3. Inflation considerations (time, temperature effects).

4. Mechanization of gas bleed to eliminate "bounce."

5. Applicable materials.

6. Inclined impact considerations (nonspherical shapes).

The above factors are vital for realizing the performance potential of pneumatic attenuators suggested by system weight and deceleration level parameters. Since the above factors are difficult to analyze, study effort might be limited to problem identification, "first-order" idealized evaluation, and definition of required experimental evaluation.

NONAXISYMMETRIC CAPSULE LOADING

Computer program development not funded by this work unit, but required for this analysis, has not been completed. The analysis is expected to be accomplished within the fourth quarter of FY 1966.

IMPACT ATTENUATOR REMOVAL MECHANISMS

To date, manpower has not been available to start this evaluation. Effort will be made to accomplish this evaluation during the fourth quarter. The capability to perform the removal operation is required by the Voyager lander. An attempt will be made to identify potential design considerations and problem areas.

HEAT SHIELD ABLATION PRODUCT INTERACTIONS ANALYSIS

Manpower has only recently been available for this study; therefore, this analysis is in the familiarization and definition stage. It is anticipated that this evaluation will be completed by the end of the fourth quarter in FY 1966.

ADVANCED PACKAGING CONCEPTS

In addition to the specific stated objectives of this work unit, but in keeping with the overall objective of evaluation and definition of areas pertinent to future projects, preliminary design evaluation of the proposed critical data recorder was supported by this work unit. Support was limited to definition of mechanical design concepts and supervision of configuration development and will end with completion of this phase of the program. Further effort in this area supported by this work unit is not anticipated.

SPACECRAFT DESIGN TECHNOLOGY

NASA Work Unit 186-68-09-06-55
JPL 384-63801-2-2920

K. H. Fishback

OBJECTIVE

The objective of this task is to develop insight into the alternative design and technology approaches for future spacecraft missions and to prepare data on these alternatives which will serve as background information during subsequent project design and mission study periods.

STUDY APPROACH

The approach in this study is directed toward extending the functional analysis technique now in use in system study and system design efforts at JPL. By means of this technique, the objectives of a mission are converted into the functional performance requirements that must be met by the system. Various combinations of the possible subsystem mechanizations capable of performing these functions are formulated, yielding a number of systems potentially capable of carrying out the mission objectives and illustrating a variety of overall system philosophies. These combinations are then examined for performance level, systems integration problems, probability of mission success, state-of-the-art, and relevant parameters.

The study tasks which have been initiated under this work unit to date are:

1. The creation of a Spacecraft Design Data Information System.
2. Mission Planning and Evaluation Methodology.
3. Redundancy Optimization Approach to Mission Planning Model.
4. Simple Spacecraft Design Redundancy Estimation Techniques.
5. Optimal Control of Planetary Entry.
6. Deep Space Mission Attitude Control and Spacecraft System Tradeoffs for Future Missions.
7. Spacecraft Asteroid Belt Protection Requirements for Future Outer Planetary Missions.

Other studies planned for initiation, but curtailed due to funding limitations late in FY 1965 and manpower limitations, to date were:

1. Spacecraft Data Handling, Processing, Control and Malfunction Detection, Isolation and Correction for Future Missions.
2. Hibernating Spacecraft Reliability.

WORK UNIT PROGRESS

The major effort in the work unit has been concentrated upon the creation of a Spacecraft Design Data Information System. This information system is expected to serve, when completed as a base of departure for the planning and development of future projects as well as establishing a base for technology advance development requirements for future missions. The information system will consist of selected data useful for project planning, advanced technical studies, and preliminary spacecraft design on 35 to 42 U. S. space projects.

During this report period previous work on data assembled on Ranger Block III and Mariner IV was completed after data verification and revisions were made. The system as it was formulated was circulated to a cross section of engineering personnel at the Laboratory with a survey questionaire for their evaluation. Personnel interviews were conducted as a result of the survey questionaire to determine the merits of the system as a reference source. The results of the survey were favorable for the system; however, as expected some constructive criticism was received. As a result of additional study of what constitutes good reference data for future efforts and comments received during the survey, a guideline document was generated which will serve to delineate more specifically the content and level of detail data in consideration of certain modifications that appear desirable.

Early in this report period an RFP was issued to industry for a Phase I effort to develop the system. Six contractors responded to the RFP which were evaluated and a contractor selected. RCA/AED was selected and a CPFF level of effort contract was negotiated for an estimated cost of $46,532. The contract was awarded to RCA at the end of December 1965. This initial contract will permit testing the contractor's ability to perform, identify the problems associated with the effort, and establish confidence at relatively low risk in the continuation of the effort. The first phase consists of (1) redesign and development of the system, (2) collection and presentation of data for 3 spacecraft projects, (3) preparation of a library of data for follow-on effort, and (4) follow-on program plan to complete system.

A study planning conference is scheduled for early in January for the contractor to present his program plan and to clarify working arrangements between RCA/JPL.

"Mission Planning and Evaluation Methodology" was completed in FY 1965, and reports have been disseminated. Use of the methodology developed in this study is currently in use by Voyager Project and in advanced technical studies.

"Redundancy Optimization Approach to Mission Planning Models," previously reported was completed, and a report is in rough draft form. At present personnel limitations have precluded a final report draft being prepared. The techniques have, however, been applied to the Voyager Project. Advanced Technical Studies have also expressed interest in its use for conceptual design studies.

"Simple Spacecraft Design Redundancy Estimation Techniques," previously reported was completed, and a report is in rough draft form. At present personnel limitations have precluded a final report draft being prepared. A computer program exists from this study which is being used by Voyager Project, and Advanced Technical Studies.

"Optimal Control of Planetary Entry," previously reported is complete in rough draft form and has been circulated to Voyager Project and Guidance and Control Division for comment. Due to apparent press of work in these areas no response has been received. The disposition of this material will be determined early in the next period.

"Deep Space Mission Attitude Control and Spacecraft System Tradeoffs for Future Missions," previously reported was prepared in rough draft form; however, the depth of study treated was not sufficient for anticipated needs of future mission tradeoff studies and redirection of the effort was made.

Spacecraft Asteroid Belt Protection Requirements for Future Outer Planetary Missions was initiated in this report period in support of current advanced technical studies. This work is programmed to be completed in the fourth quarter.

"Spacecraft Data Handling, Processing, Control and Malfunction Detection, isolation and correction," previously planned for study will be considered in the next quarter for study with the possible acquisition of a qualified new employee. This study will be reconsidered in light of new and future project requirements. Contractor assistance will be used for the study.

Other study plans are in the process of being formulated in support of project and study goals that will be reported in the next report period.

HIGH-IMPACT MECHANICAL TECHNOLOGY

NASA Work Unit 186-68-10-03-55
JPL 384-65601-2-3550
J. L. Adams
M. G. Comuntzis

OBJECTIVE

The objective of this task is to develop the technology necessary to allow the building of mechanical spacecraft equipment capable of surviving high impacts (10,000 g, 500 ft/sec ΔV). Lunar and planetary landers (such as future Mars landers) will contain mechanical equipment in instruments, erection systems, recorders, and actuators. In order to properly design such landers it is necessary to have knowledge concerning the penalties paid for ruggedization. This knowledge becomes design knowledge for a hard lander. It becomes tradeoff knowledge for a soft lander. In any case it contributes to overall equipment ruggedness. This effort will provide such knowledge.

PROGRESS

Figure 1 is an exploded view of an improved air turbine constructed to test the feasibility of operating a rotating device during impact. This turbine consists of an 8-oz rotor supported between spring centered bearings. The turbine has been impacted at 10,000 g from 170 ft/sec in the axial and radial directions while operating at approximately 30,000 rpm. Negligible bearing damage occurred during the test. Damage to the turbine and housing was small. The major impact loads, of course, were absorbed by bottoming between the rotating mass and the housing.

Figure 2 shows a *Ranger* Block I titanium pressure tank which was modified and tested under impact. A 0.200-in.-thick by 0.300-in.-wide titanium ring was welded to the circumference of the tank. The tank was then clamped in a fixture by this ring and impacted both normal to the ring and parallel to the ring. The tank was tested empty and unpressurized at g levels up to and including 10,000 from 150 ft/sec with no apparent damage. It was then pressurized to 3,000 psi with water and impacted in both directions at 10,000 g from 140 ft/sec with no apparent damage. No pressure gages or strain gages were flown, so it is impossible to know whether yielding of the titanium was sufficient to lower the pressure in the bottle.

Figure 3 shows a pressure regulator developed for low flow rates and stability under high impact. The regulator is a two-stage device which utilizes diaphragms both for pressure sensing and spring force. The pressure regulator shown is capable of regulating a supply at several thousand psi to outputs on the order of 60 psi at low flow rates (50 ml/min). Regulation is within 1/2 psi at the output over an input range of 200 to 1500 psi. The regulator has been impact tested at 10,000 g from 200 ft/sec both axially and radially. Regulation has remained within 1 psi over the 200-1500 psi input range.

Work accomplished in this work unit during this report period is mentioned in SPS 37-35, Volume IV, JPL TR 32-844, *The JPL High Impact Program-1965,* by J. L. Adams, and in a paper entitled "High Impact Spacecraft Equipment," by J. L. Adams and M. G. Communtzis, delivered at the 35th Shock and Vibration Symposium at New Orleans on October 27, 1965.

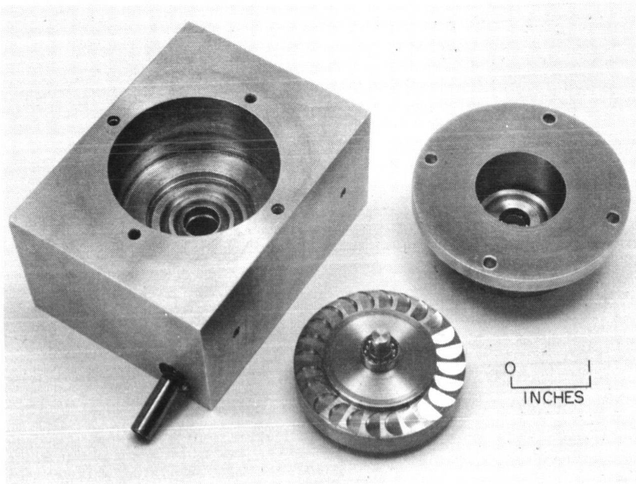


Fig. 1. Improved air turbine

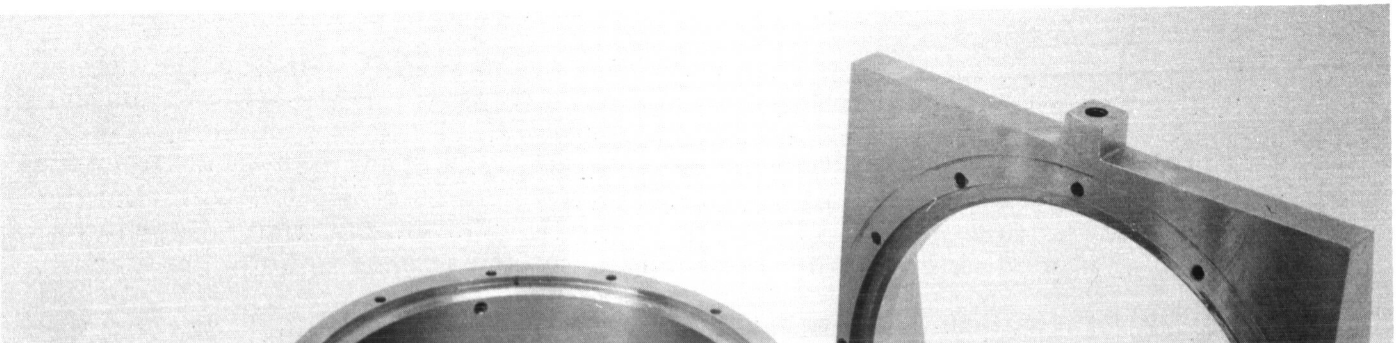


Fig. 2. Ranger Block I titanium pressure tank

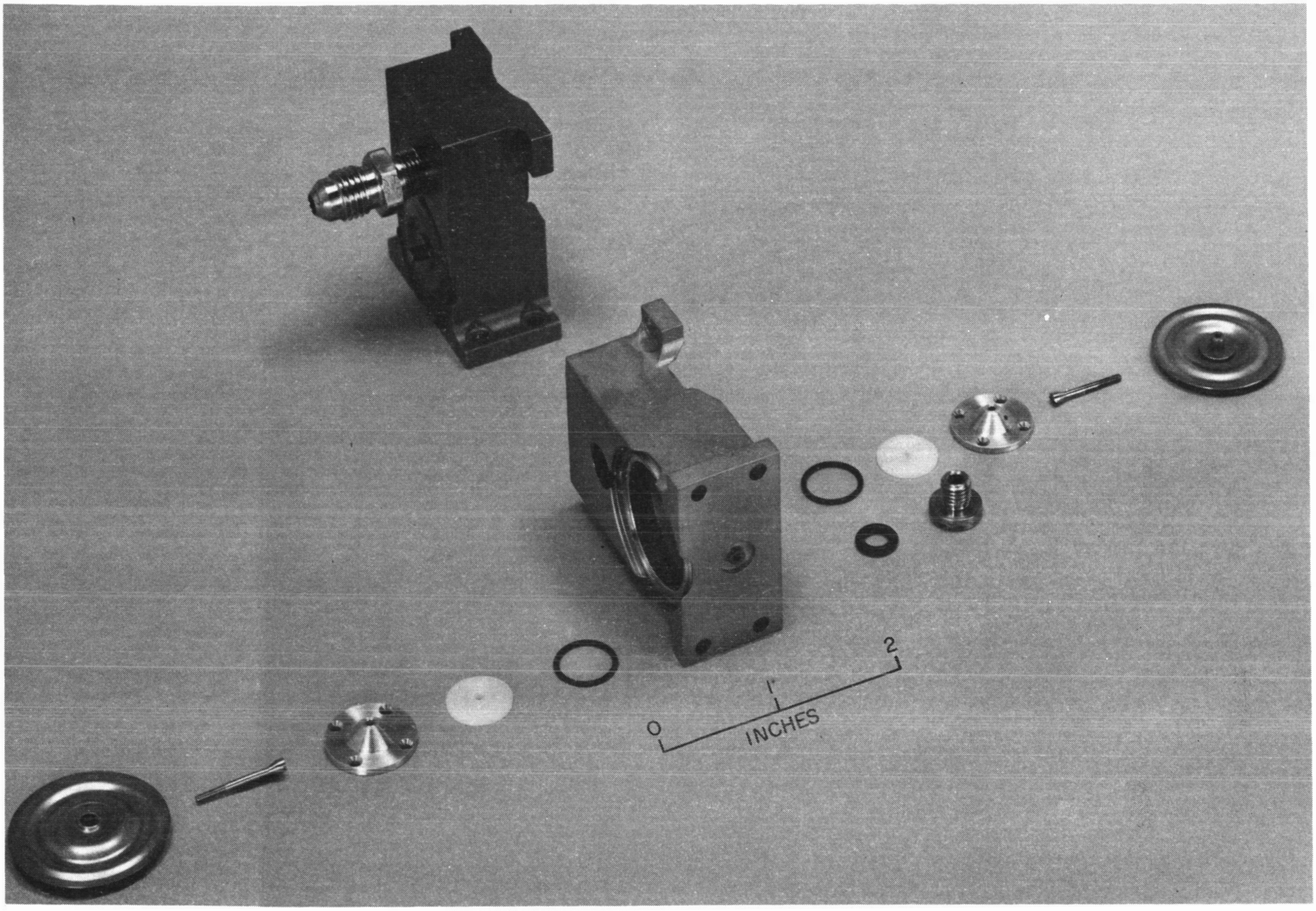


Fig. 3. Pressure regulator

HIGH-IMPACT TESTING

NASA Work Unit 186-68-10-04-55
JPL 384-65701-2-3550

J. L. Adams
M. G. Comuntzis

OBJECTIVE

The objective of this task is to provide the testing needed in conjunction with the development of high-impact (10,000 g's, 500 ft/sec ΔV) technology. In order to properly design any lunar or planetary unmanned lander (such as the Mars '71 lander) it is necessary to understand the response of spacecraft equipment to impacts. The penalties paid for ruggedization must be known before lander design tradeoffs can be intelligently made. Due to geometrical complexity and the unavailability of suitable analytical tools, a great part of this effort must be of an experimental nature. This effort will accomplish such experimentation and develop the necessary test equipment.

PROGRESS

During this report period, 246 high-impact tests were performed at JPL. These tests supported various high-impact development efforts as shown below:

High-Impact Communications Subsystem Technology	92 tests
High-Impact Scientific Instrument Technology	2 tests
High-Impact Battery Technology	23 tests
High-Impact Mechanical Technology	19 tests
High-Impact Electronic Packaging	37 tests
Miscellaneous	73 tests

The miscellaneous tests included both component investigations and testing technology development. Components tested included microcircuits, relays, and squibs. The testing technology development included strain-gage work. Strain gages have not been used in past high-impact work at JPL. However, an effort is presently underway to increase our understanding of the limitation of various analytical tools when applied to shock. Strain gages are a useful tool in this effort. Figure 1 shows a strain-gage accelerometer which was developed and tested in conjunction with the strain-gage work. This device consists of a thin-walled tube with a lead weight in the upper end and a mounting flange at the bottom. Strain gages are placed on the inside of the tube below the weight so that they measure compressive strain due to axial inertial forces. Acceleration-vs-time curves obtained from this device compare nicely with those obtained from the standard piezoelectric accelerometers.

Figure 2 shows the 22 in. compressed air gun fitted with a pusher for testing air-bag decelerators. The pusher consists of a piston, a shaft, and a basket. The piston is accelerated down a 6-ft barrel and then stopped by crushable material placed in the perforated sleeve. The test item is then allowed to fly free to the impact.

Work accomplished in this work unit during this report period is mentioned in SPS 37-35, Volume IV, JPL TR 32-844, The JPL High Impact Program-1965, by J. L. Adams, and in a paper entitled "High Impact Spacecraft Equipment," by J. L. Adams and M. G. Comuntzis, delivered at the 35th Annual Shock and Vibration Symposium at New Orleans on October 27, 1965.

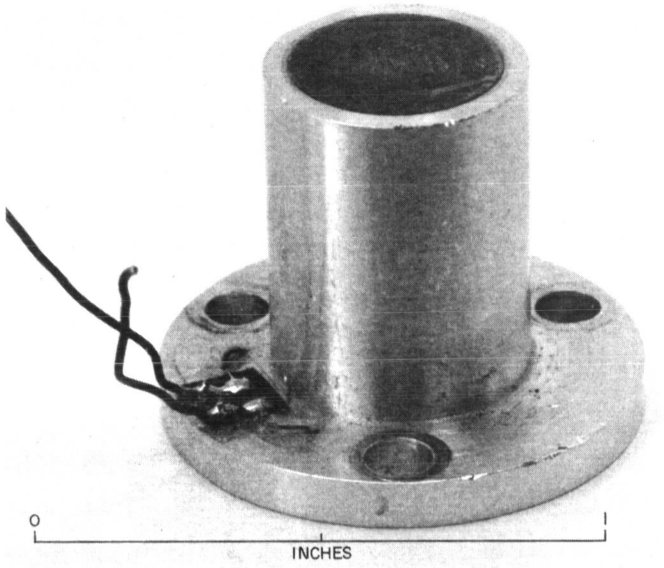


Fig. 1. Strain gage accelerometer

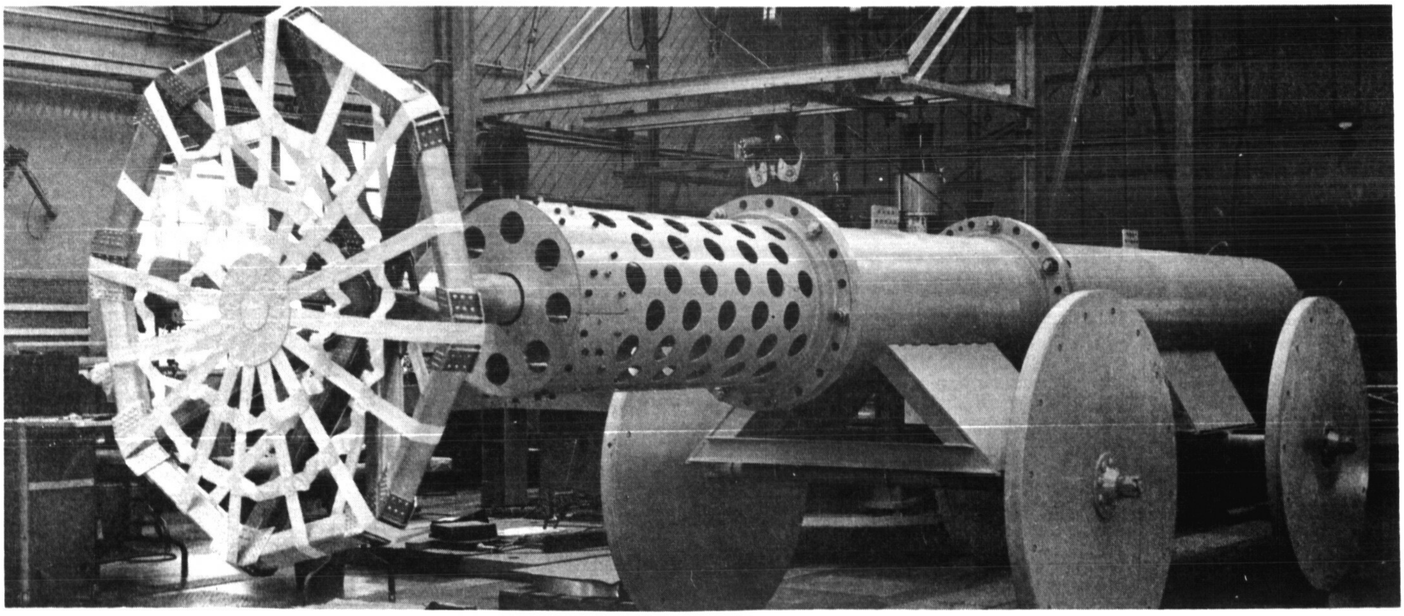


Fig. 2. 22-in. air gun

HIGH-IMPACT ELECTRONIC EQUIPMENT PACKAGING TECHNOLOGY

NASA Work Unit 186-68-10-06-55
JPL 384-65901-2-3570
R. C. Mayne

OBJECTIVE

The long-range objective of this work unit is to design and develop spacecraft subsystem and subassembly electronic packaging and cabling technology that will allow hard lander capsule equipment to reliably survive high impact (10,000 g's, 500 ft/sec ΔV) with no damage or degradation. The initial objective for FY 1966 was to develop the technology for "typical" subsystem electronic packaging and cabling requirements in support of the Voyager Program, and standard packaging techniques were to be developed and qualified. The objective for FY 1966 has been redirected to support the Surveyor Program, and a preliminary mechanical design of a high-impact critical data recorder (CDR) was initiated. The present FY 1966 task objective is to design and develop the high-impact CDR capsule system configuration, and the effort will include packaging and cabling design, connector development, antenna packaging, mechanical integration of the electronic subsystems, and mechanical integration of the impact limiting shell to the electronic system.

MODULAR PACKAGING

A preliminary design study of a mechanically integrated modular electronic subsystem packaging configuration for the Voyager lander was completed. Elements of this configuration were utilized in the JPL baseline lander design.

Embedded welded cordwood modules of several configurations were designed, fabricated, and tested. Figure 1 shows a typical "slingshot" test setup for testing embedded modules under shear impact loads; this particular configuration went through 11,000 g testing with no failures. The development goal for high-impact embedded module development is 20,000 g's (in order to reliably permit 10,000-g designs), and the results to date indicate that this goal is readily achievable. Two module embedment materials are presently being evaluated for the high-impact environment; one is Stycast 1090/11, which has much use history on JPL spacecraft, and the other is a lower density syntatic foam resin system developed by JPL Section 357.

Mechanical elements of typical high-impact modular electronic subassemblies were designed, fabricated, and successfully tested. Figure 2 shows a test fixture and typical mechanical elements of 7- and 5-in.-wide subchassis. Figure 3 shows the 7-in. element with associated modules installed in the test fixture; this configuration withstood 10,000 g's, and the 5-in. element successfully passed a 15,000-g impact test. In all configurations which were designed and tested, the welded modules were integrated into the subassembly structural members as reduced stress load sharing members by the use of a semi-rigid adhesive within each common interface.

Development and evaluation of techniques for mechanical support of discrete components was initiated in support of electronic circuits which can best be packaged in a flat layout geometry (low component density power converters, etc.). As a first step, a high-impact evaluation was made of Solithane 113/300 (Formulation 1) used as a basic conformal coating to support discrete components of a typical size range.

Figure 4 shows the test fixture and component arrangement first used. All component leads were removed to ensure that no mechanical support was gained through these leads. For high impact, it is required that all component bodies are mechanically supported to ensure strain relief of their associated leads. Tests were performed in increasing 1000-g increments in an axis perpendicular to the circuit board, and in the direction away from the mounting surface. No failures occurred until 5000 g's, and most of the components were in place after the test was terminated at 15,000 g's. Evaluation and test to date indicates that the problem of discrete component support in the high-impact environment is easily satisfied.

CRITICAL DATA RECORDER

The mechanical design of a high-impact critical data recorder for the Surveyor spacecraft was initiated. The mechanical configuration of the CDR is an integrated assembly containing six contoured outboard facing cavities for mounting antennas, facing in opposite directions on three mutually perpendicular axes. The battery, sensors, and the electronics subsystems will be designed into modular subassemblies which will be mechanically integrated to form the system assembly structure.

System interconnection will be effected by use of hard-mounted cable harnesses and semirigid coaxial cable assemblies. Both ruggedized connectors and discrete solder joints will be further studied to determine the best interconnection technique for joining the system cable harnesses to the electronic subsystems. External connectors will be used for interconnection to the spacecraft-mounted antenna and the touchdown-dynamics sensors. OSM miniature coaxial connectors (OMNI-Spectra, Series 200-249) have been evaluated and tested at 10,000 g's with good results. There was no degradation of electrical performance due to impact testing, but mechanical degradation was observed in the solder joint between the 0.141-in.-diameter rigid coaxial cables and the connector bushings (Fig. 5). This connector type has been redesigned to eliminate this potential failure mechanism. Figure 6 shows the test setup for the subminiature rectangular connectors and associated hard-mounted cable harnesses.

It is planned to use several techniques to package and interconnect the components within the modular subsystems:

1. Rigidly encapsulated welded cordwood modules.
2. Terminal-connected point-to-point three-dimensional layout with minimum-length critical conductors and solder joints.
3. Weld-interconnected integrated circuit configuration.

The high-impact configuration will be fully enclosed within an outer layer of an RF-transparent impact-energy-absorbing material such as balsa wood. A thin (0.020 in.) external structural skin of epoxy-fiberglass will be used to distribute external concentrated loads to the impact-energy-absorbing material.

During flight, temperature control of the subsystem will be mainted by the designed absorptivity and emissivity of the outer surface. During the operating life of the system on the lunar surface, the thermal mass of the system will be utilized to maintain temperatures within the specified limits.

The mechanical design and development effort will be continued for the configuration, electronic packaging, and cabling of the critical data recorder. The work effort will include the following areas:

1. Battery packaging design.
2. Connector development and testing.
3. Cabling design.
4. RF electronic equipment packaging.
5. Antenna packaging.
6. Integrated circuit logic packaging.
7. Ferrite core memory packaging.
8. Mechanical integration of the electronic subsystems.
9. Mechanical integration of impact limiting shell materials(s) to the electronic system.

The technology developed in this task will directly support the electronic packaging and cabling development for future spacecraft hard lander capsule system requirements.

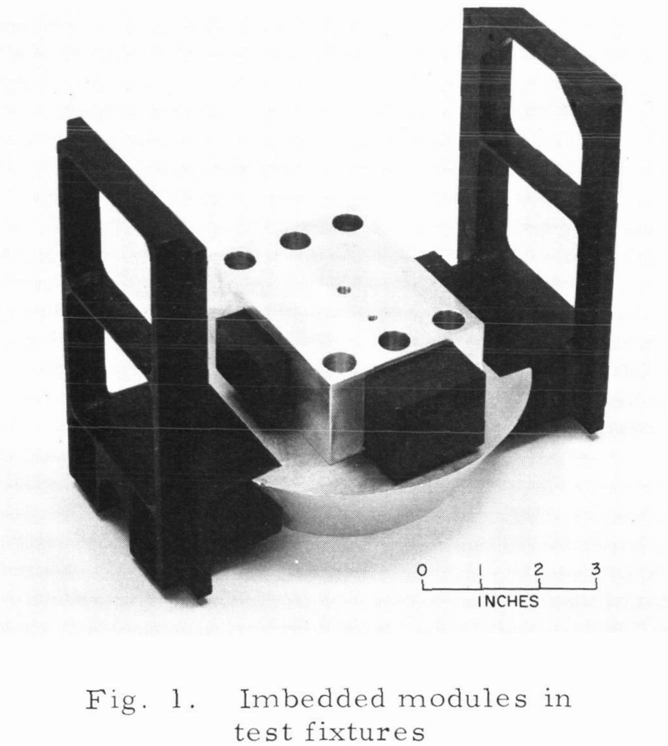


Fig. 1. Imbedded modules in test fixtures

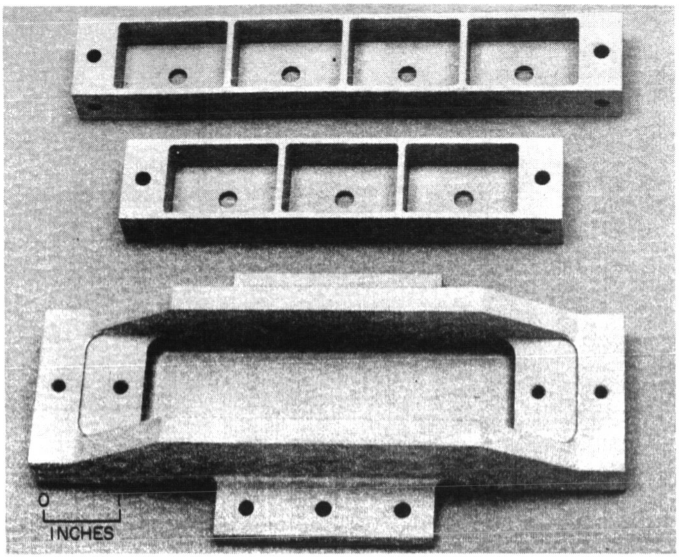


Fig. 2. Mechanical elements of 7- and 5-in.-wide subchassis

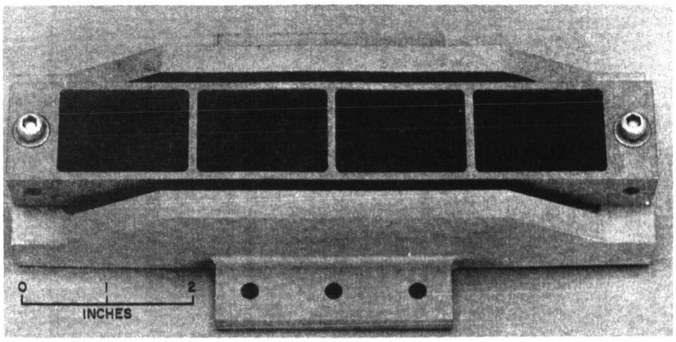


Fig. 3. Subchassis mechanical elements with modules installed

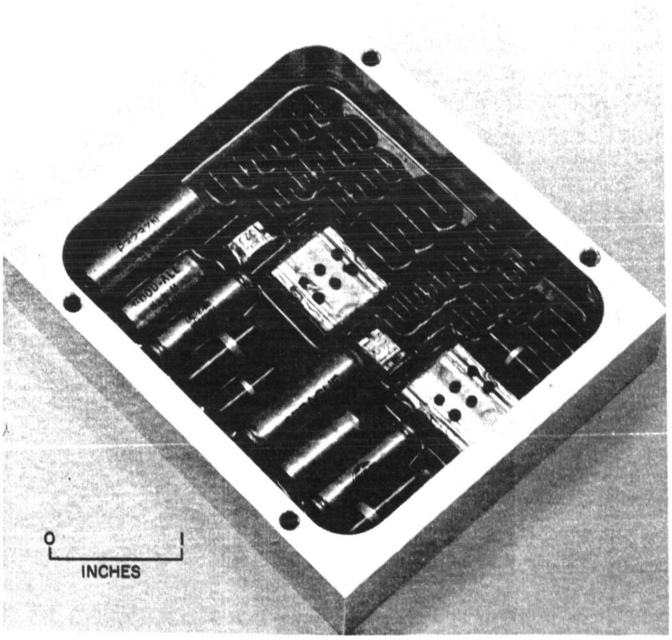


Fig. 4. Discrete components mechanically supported by conformal assembly

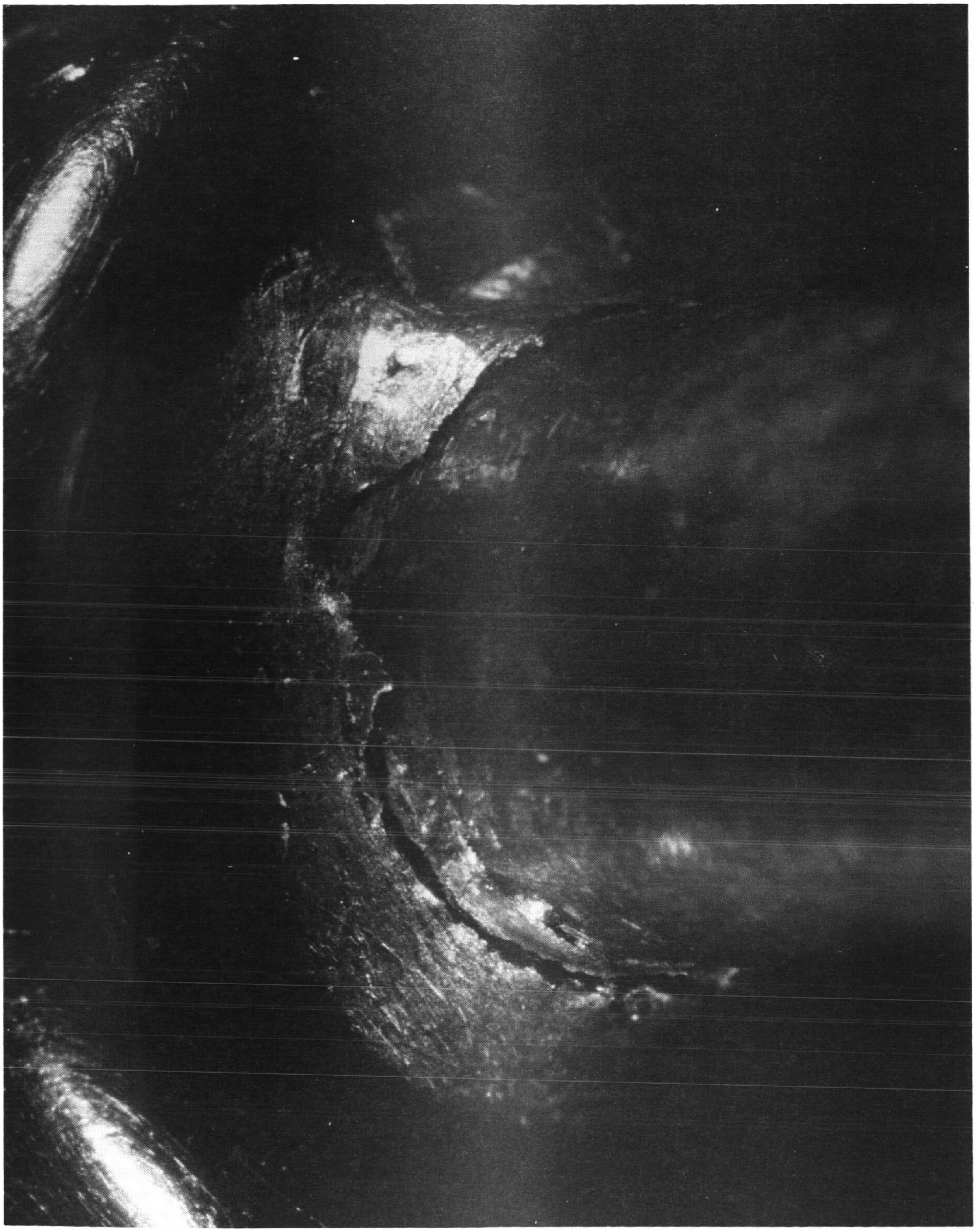


Fig. 5. Mechanical degradation of miniature co-axial assembly

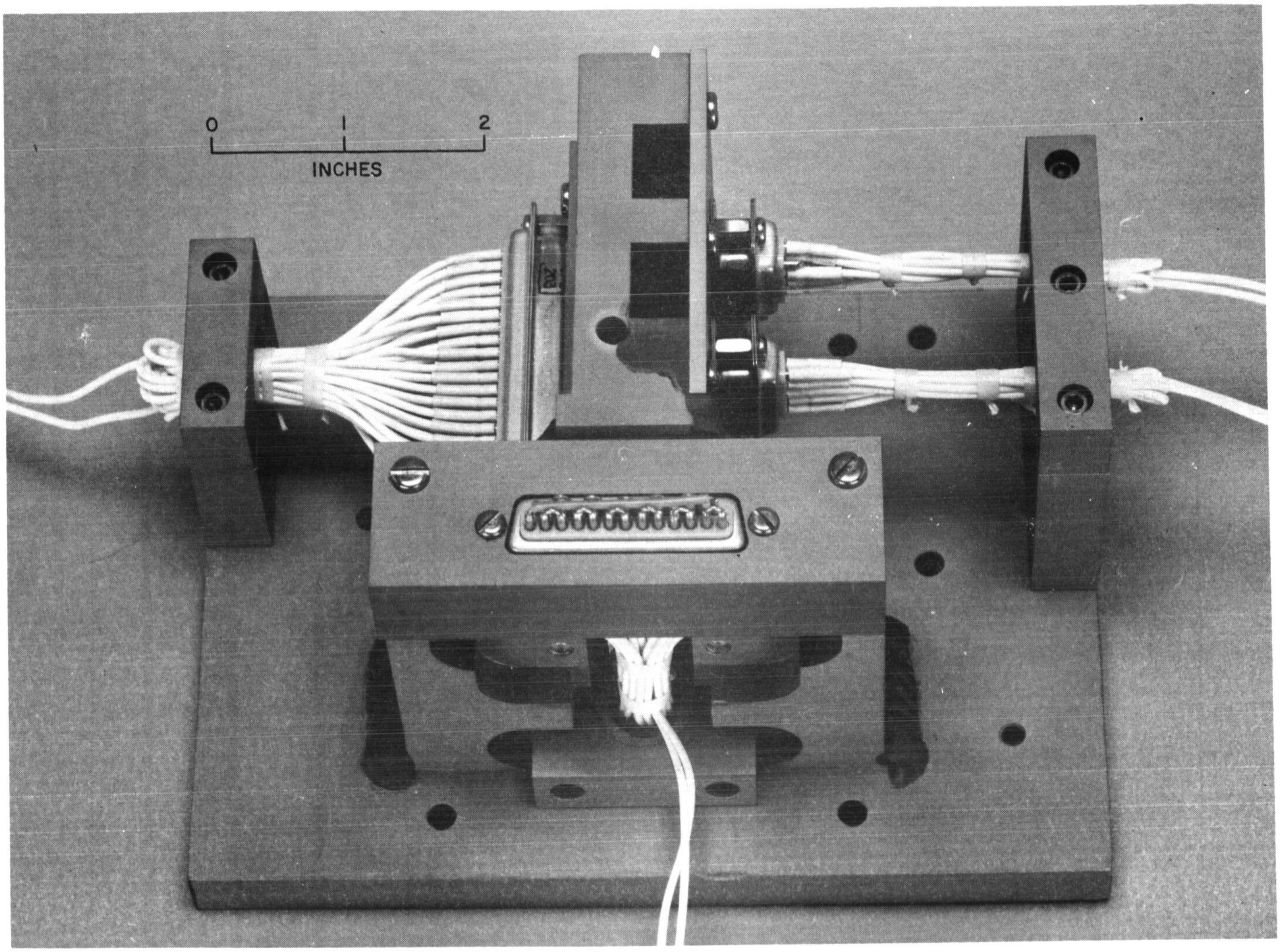


Fig. 6. Test fixture for subminiature rectangular connectors and associated wiring

HIGH-IMPACT DEMONSTRATION LANDING PAYLOAD

NASA Work Unit 186-68-10-07-55

JPL 384-66201-2-3550

J. L. Adams
M. G. Comuntzis

OBJECTIVE

To develop the technology necessary to allow the building of high-impact (10,000 g's, 500 ft/sec ΔV) resistant capsule payload and diagnostic package systems. Mechanical and electrical hardware interfaces will be investigated under high impacts. This knowledge is necessary for the proper design of any lunar or planetary lander (such as future Mars landers). The function of this effort will be to investigate items of a complex and cross-discipline nature. This work unit will not only produce knowledge, but also uncover problems and help orient the JPL high-impact program.

PROGRESS

During this report period circuit diagrams were completed for a simple demonstration rough landing payload containing the gas chromatograph, temperature and pressure sensors, a battery, power conversion and regulating equipment, sequencing, signal amplification, a voltage controlled oscillator, and a transmitter. Various portions of the circuitry were developed through the breadboard stage. The pressure and temperature transducers, the VCO, and miscellaneous specialized components were purchased for evaluation. Figure 1 is a schematic of the payload. However, work was halted because of the onset of study work on a Surveyor diagnostic package.

During this report period, a conceptual study and a preliminary design were completed on a critical data recorder system for the Surveyor spacecraft. This system was designed so as to return touchdown data from Surveyor independently of the primary Surveyor communication link. The data would be for the purpose of answering two questions:

1. If failure occurred, what should be done to the next Surveyor?

2. What is the nature of the lunar surface?

The proposed recorder itself consists of a battery, an S-band transmitter, omnidirectional accelerometers, an inclinometer, multiple antennas, an antenna switch, and sufficient electronics to handle the data from the various sensors. These sensors, in addition to the accelerometer and inclinometer in the recorder package, consist of digital sensors to measure contact with the lunar surface and failure of structural elements such as legs, antenna booms, and electronic package mounting struts. In addition to antennas mounted in the recorder package, one antenna is mounted upon the spacecraft.

The data handling electronics include the capability of recording the approximate time of occurrence of several of the sensor outputs (the time of closure of the contact sensors, time of occurrence of key structural failures, and time of appearance and disappearance of various acceleration levels). The time-correlated data

and data from change of state sensors (the inclinometer, peak deflection of oleo struts, additional structural failures) is used to modulate the transmitter at a low information rate. The information is transmitted in turn over each antenna for several cycles. The recorder package will be ruggedized to survive several thousand g's of impact and will weigh approximately 12 lb.

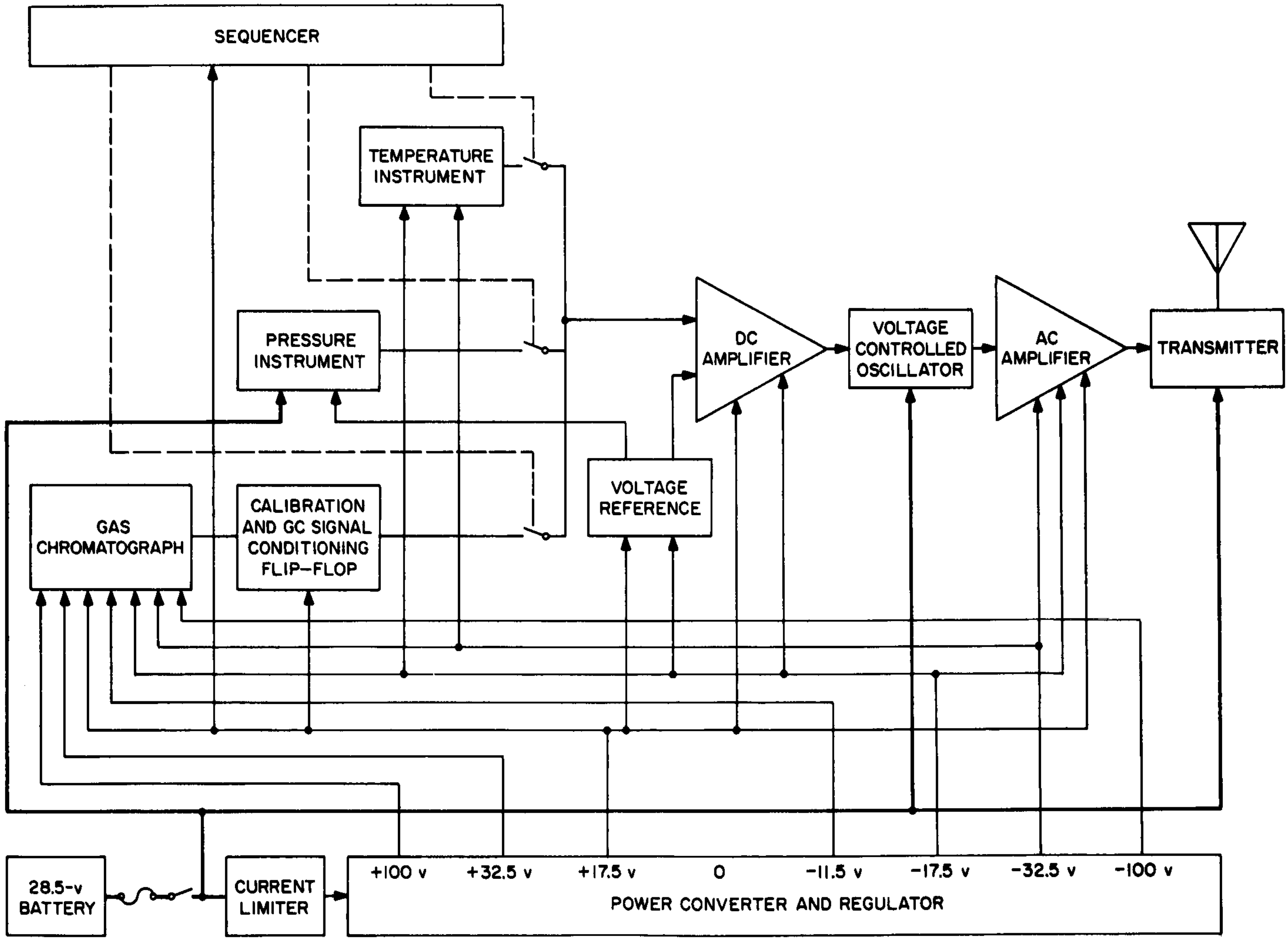


Fig. 1. Block diagram of high-impact demonstration payload electronics

MODULAR WELDED PACKAGING ADVANCED DEVELOPMENT

NASA Work Unit 186-68-10-09-55
JPL 384-66601-2-3570

R. C. Mayne

OBJECTIVE

The objectives of this task are to design and develop an optimized mechanically integrated nonmagnetic welded matrix configuration for Voyager based on the recently developed gamma ray spectrometer pulse-height analyzer welded matrix design, and to complete a detailed thermal study of welded cordwood modular assemblies.

WELDED MATRIX SUBASSEMBLY DEVELOPMENT

The welded matrix modular interconnect concept originated in the desire to provide a design technique to interconnect welded modules with a welding process (rather than soldering) and yet provide a module replacement capability without degradation of hardware as may occur in an etched circuit board with soldered connections. The matrix provides an interconnect assembly with all conductors in defined locations and thus offers a benefit as compared to a wire harness interconnect scheme.

Figure 1 shows the welded matrix modular packaging configuration in its present state of development at JPL. Each welded module lead is insulated from the magnesium chassis and interconnect matrix conductors by use of a plastic insulator. After fabrication, the welded matrix is cast in place with an epoxy resin system into the magnesium chassis to form a structurally integrated assembly. The welded modules are bonded in place with a viscoelastic adhesive to provide additional subassembly stiffness and to provide structural damping. The module leads are interconnected to the external matrix conductors by use of welded straps as shown in Fig. 2.

The mechanical prototype pulse-height analyzer decoder subassembly was completed, and environmental testing was conducted at levels up to 50 g rms O-peak sine sweep 20-2 kc with no damage or degradation; the transmissibility at the fundamental resonant frequency is extremely low (1.5) due to the viscoelastic damping incorporated into the design. The electrical prototype has been completed.

A typical example of flight type hardware with an interconnection density considerably greater than the pulse height analyzer decoder has been selected for the second design and fabrication exercise. A portion of the Mariner C data automation system required approximately twice the module interconnection density as previously considered in this development effort. Although the techniques of assembly remained the same, more effort was required in the detail design, due to the need to control tolerances to tighter limits to insure the same ease of fabrication as previously experienced. Figure 3 shows a data automation system welded matrix before encapsulation.

The conductor material selection draws upon the efforts of the Electronic Packaging Advanced Development Task and at present consists of a 0.010 x 0.030-in.

Cupro-nickel alloy (11% Nickel) which provides a very satisfactory welding process to the riser or external connections which are gold-plated, oxygen-free copper.

The degree of complexity of the welded wire matrix interconnections required four layers of conductors which did not prove to be a handicap in the assembly phases.

The fabrication development has proceeded through the assembly and welding of the conductors, and no difficulties arose in this phase of assembly. The remaining manufacturing development tasks lie almost entirely with the embedment processing of the interconnect assemblies. Several different approaches to the embedment tooling are being investigated which vary in the degree of structural integration of the interconnect assembly. A materials development effort is in work to attempt to find an embedment material of reduced density in order to lower the total weight of the interconnect assembly.

In the remainder of FY 1966, the welded matrix electronic packaging concept will be developed further for future spacecraft system applications, and the following tasks have been engaged:

1. Study the effects of varying geometry and the degree of structural integration and damping on dynamic characteristics of the subassembly.

2. Continue nonmagnetic conductor material and size study for more optimum joining process.

3. Develop more optimum welded module attachment techniques.

4. Attempt to develop matrix configuration with reduced numbers of required interconnections.

5. Develop more optimum welded module embedment techniques.

6. Thermal test modules have been fabricated with integral thermocouples which will be used to obtain detailed thermal characteristics. The thermocouple junctions are attached to resistor bodies within each modular embedment. Thermal profiles for typical modules will be obtained for all predictable conditions of component heat dissipation requirements.

7. Welded matrices and modules are being fabricated to further develop and qualify this configuration to insure that physical integrity is reliably maintained under environmental stress.

The results of this development effort to be completed in FY 1966 will be reflected in JPL Design and Process specifications.

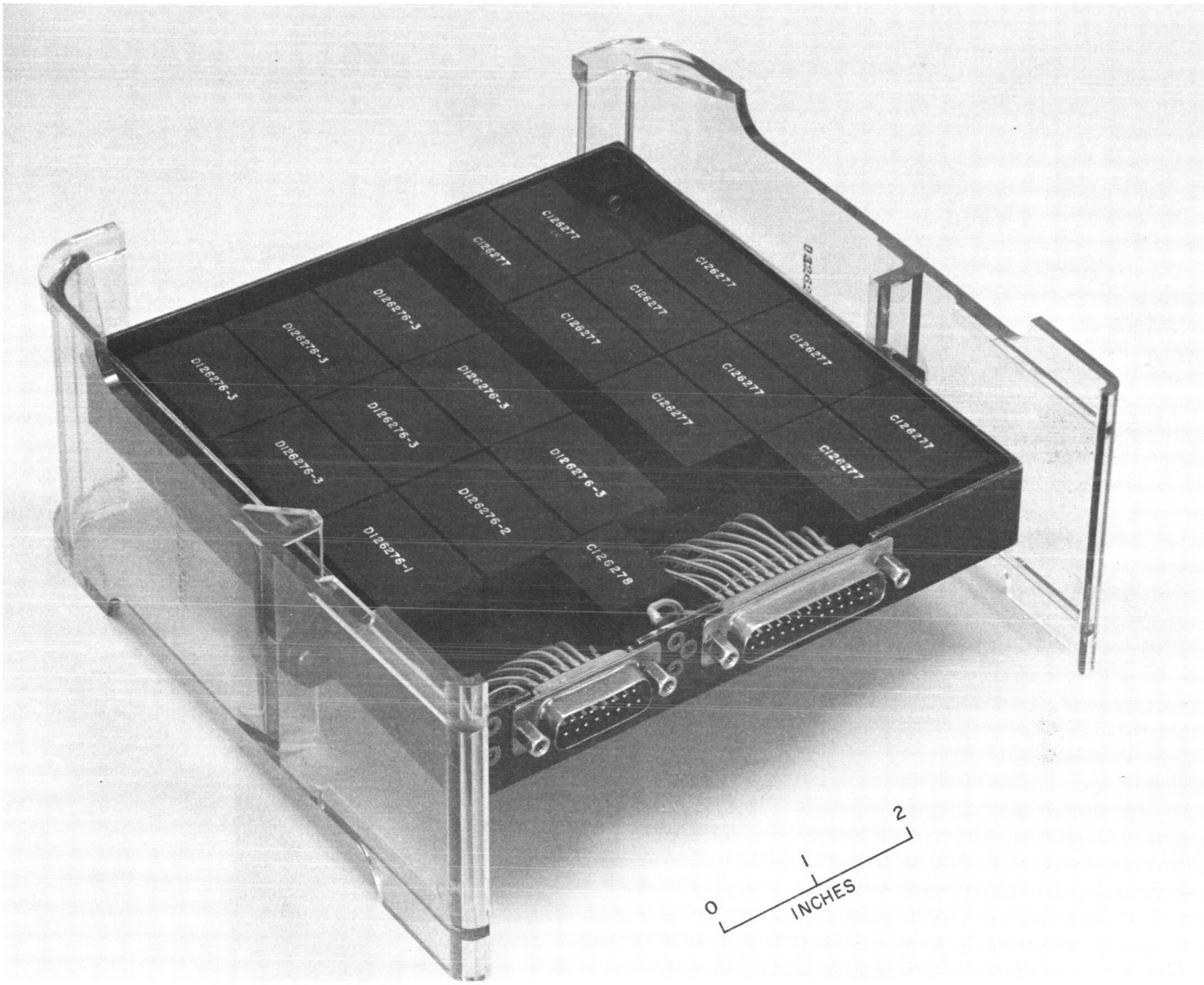


Fig. 1. Welded prototype, PHA decoder subassembly (front)

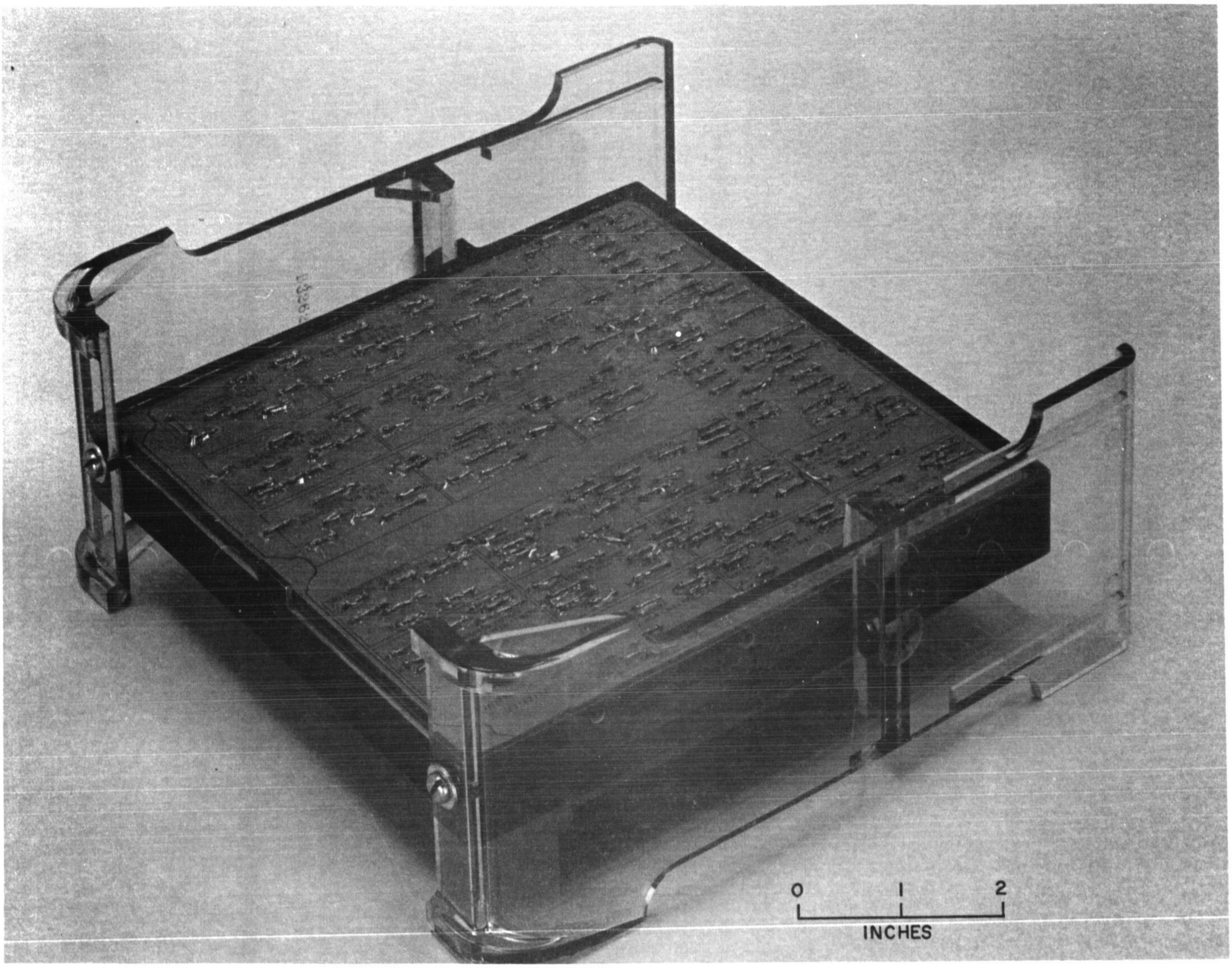


Fig. 2. Welded prototype, PHA decoder subassembly (back)

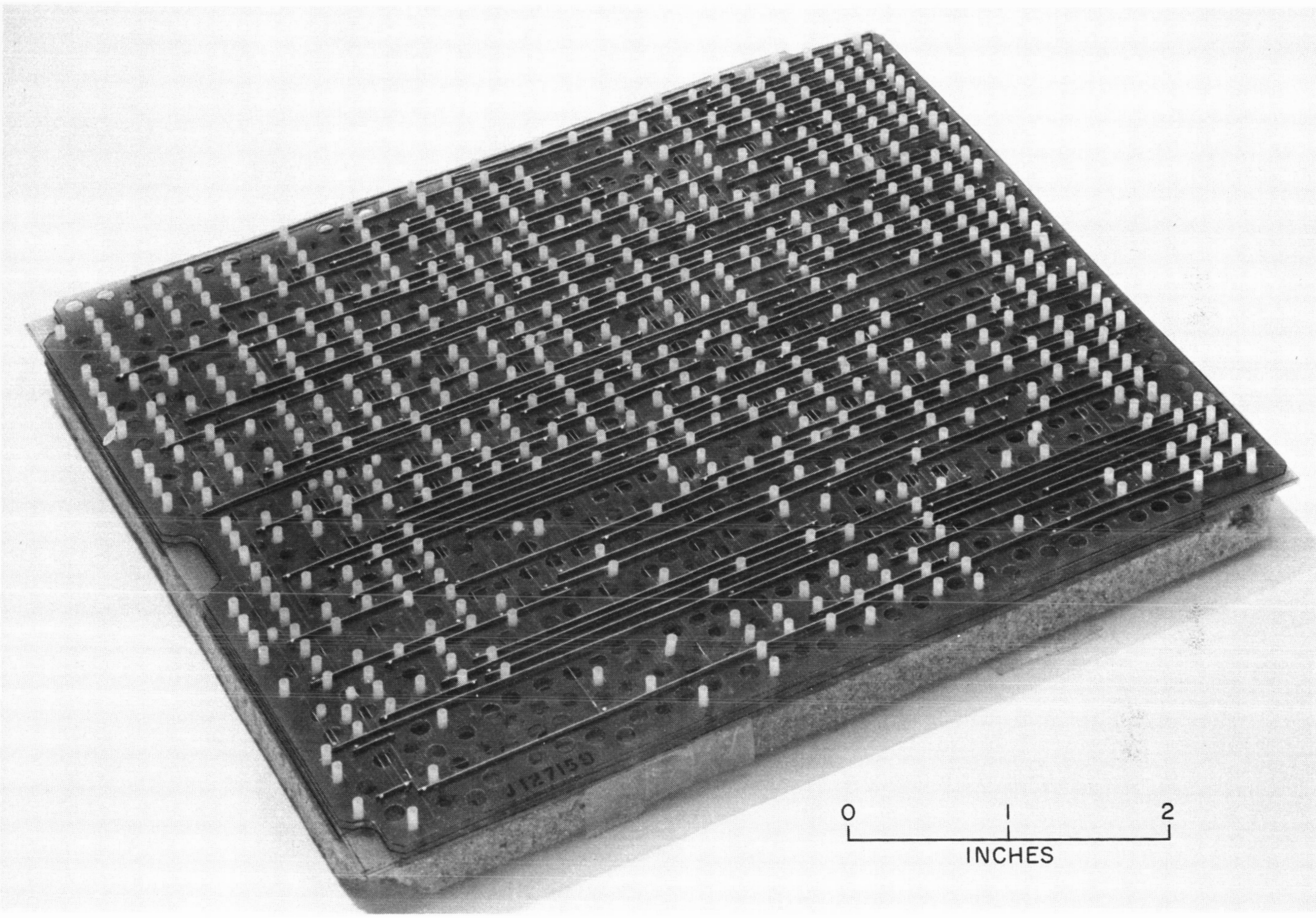


Fig. 3. Welded matrix during fabrication

PLANETARY ENTRY AERODYNAMIC DECELERATION

NASA Work Unit 186-68-13-01-55
JPL 384-62501-2-3530

J. M. Brayshaw

OBJECTIVE

The objective of this task is to reduce uncertainties in the design of auxiliary decelerators for terminal descent. For this fiscal year, the specific objectives include the determination of the applicability of trailing-balloon and expandable vehicle auxiliary decelerators including systems specifications and possible prototype design fabrication, the study of the effects of porosity and light canopy loading on the inflation behavior and and swaying stability of subsonic parachutes in a low-density environment, and the examination of problems associated with pyrotechnic devices and other alternatives.

ACTIVITIES

Effort in this work unit for the first half of FY 1966 has been directed toward:

1. Determination of applicability of expandable decelerators for Mars atmosphere entry.
2. Selection of an initiator system to sense conditions for release of a decelerator.
3. Study of parachutes for transonic deployment.

Because of manpower diversions to the Voyager Project, no work was done on sterilization problems of pyrotechnic devices.

APPLICABILITY OF EXPANDABLE DECELERATORS

Because of the low density of the Mars atmosphere, large amounts of an entry capsule structure must be devoted to providing sufficient drag area to decelerate the entry payload to an acceptably low impact velocity either for direct impact or for deployment of a decelerator. It is expected that expandable structures, either a towed ballon-type or an expandable extension of the basic entry capsule structure, can be deployed after maximum entry trajectory deceleration for the purpose of augmenting the basic capsule drag area. By exposing the added drag surfaces only to reduced loads and heating after worst entry conditions, it is expected that residual internal payload may be increased beyond that available if the entry capsule had to produce to overall required drag impulse.

Under a contract awarded to Goodyear Aerospace Corporation (with FY 1965 funds), study of the effectiveness and weight efficiency of balloon expandable structures has been started.

A number of conceptual designs of both towed balloon and expandable capsule skirt types will be generated, appropriate to deployment conditions encountered along a series of ballistic entry trajectories furnished by JPL. These entry

trajectories were selected to provide the maximum expected spread in Mach Number Dynamic Pressure deployment conditions consistent with expected spread in entry velocity, path angle, and atmosphere models.

Because this study leads directly to present *Voyager* plans for supersonic decelerator development, follow-on funds provided for in this year's budget have been set aside for use by the *Voyager* program office. This plan was described at the first quarterly oral report.

SELECTION OF INITIATOR SYSTEM FOR DECELERATOR RELEASE

A more sophisticated sensing and deployment initiation system than that used on Earth isnecessary for Mars flights because of large tolerances in our knowledge of Mars atmosphere properties at a given altitude and also because of possible inaccuracies in Mars entry trajectories. This initiator system may take the form of a small capsule on-board computer to correlate the possible histories of flight condition variations and determine time for safe deployment while maximizing remaining altitude or descent time.

Northrop Corporation — Ventura Division, has started work on a contract study to examine various possible combinations of flight sensors and logic systems. The deployment conditions to be sensed are inferred from JPL ballistic entry trajectories. Initiator systems appropriate to both single stage subsonic, and two stage supersonic-subsonic decelerators will be examined. Component accuracies and reliability will be considered. Conceptual design drawings of selected systems will be prepared.

STUDY OF PARACHUTES FOR TRANSONIC DEPLOYMENT

A Request for Proposal for a contract study of the inflation, stability and design problems of a low speed parachute to be deployed at transonic speeds is in preparation. The execution of this study is dependent of final working arrangements with the NASA Langley Research Center in the area of decelerator development for the *Voyager* program.

SPACECRAFT MATERIALS EVALUATION

NASA Work Unit 186-68-13-03-55
JPL 384-62701-1-3820
J. Moacanin

OBJECTIVE

The objective of this work unit is to provide a service group that can quickly develop or test prototypes of polymeric materials required in various Voyager and Surveyor components. To provide as wide a range of assistance as possible, problems that appear soluble in six months or less are being emphasized.

FOAM ENCAPSULANTS

Objective: To assess the outgassing characteristics in high vacuum of foam encapsulants, and determine their resistance to corona discharge and electrical breakdown.

Experimental weight loss vs time data for outgassing in high vacuum CO_2 from polyurethane foams have been analyzed using diffusion equations developed during the previous period. It was concluded that a single diffusion constant D describes the transport process; but for short times for very low density foams ($\rho \sim 2$ lb/cu ft) there is marked nonideal diffusion. Furthermore, using the equation $D = \text{constant} \times P_e/\rho$, the value of P_e, the permeation constant for the bulk polymeric material was calculated from foam diffusion data and found to agree with that determined directly on the bulk polymer. This important result ascertained the validity of our equations and demonstrated that the diffusion constant for a foam of given density could be calculated from P_e for the bulk polymer.

The experimental setup for diffusion measurements at elevated temperatures has been tested. Results indicate a drastic increase in outgassing rates with increasing temperature. A 4.5 lb/cu ft foam lost about 98% of its gas content in 180 hr at 81° C, as compared to 57% at 22° C.

This work has been published in SPS 37-34, -35, and -36, Vols. IV, and presented to the NASA Workshop on Voltage Breakdown in Electronic Equipment at Low Air Pressures, JPL, August 1965, the Canadian High Polymer Forum, September 1965, and to NASA-OSSA in November 1965. A technical report is in print. A paper will be presented at the Society of Plastics Engineers Meeting, Montreal, Canada, March 1966.

For the studies on electrical behavior, a corona network was calibrated for a range of pressures with both N_2 and CO_2. Electrodes (3/32 in., brass rods, rounded at the ends) were 1 in. apart. For pressures above 50 mm Hg, CO_2 exhibited onset of corona at a voltage considerably higher than that for N_2.

The same electrode configuration was used inside cylindrical polyurethane foam specimens. For these experiments techniques for potting electrodes had to be developed because attempts to foam in place were unsuccessful. Visible electrical discharge could be observed inside the foam specimens. Results of the tests carried out thus far are inconclusive, since in some cases breakdown was

observed at about 10 kv with the specimens at atmospheric pressure. From ASTM test results a breakdown voltage of about 40 kv should have been expected.

For future work, the effect of electrode configuration on the breakdown behavior will be investigated. Then a study will be carried out on corona and breakdown on polyurethane foams of varying densities, both at atmospheric and reduced pressures. The behavior of other foam materials, such as polyethylene will also be studied.

STERILIZABLE ELASTOMERIC FOAMS

Objective: To prepare elastomeric foams which are stable at elevated temperatures (ca. 150° C), in support of the effort on the development of sterilizable solid propellants for Voyager capsule applications. These foams are to be tested as potential propellant liner materials capable of relieving thermal stresses during sterilization heat cycles.

It has been found that elastomers prepared from PBAA[1] and MAPO[2] could withstand the high temperature sterilization treatment with a reasonable retention of properties. Generally, higher properties are retained as the concentration of MAPO is lowered. During sterilization, these materials are characterized by a hardening and darkening of the exposed surface which gradually advances inward with increasing exposure times. Based on modulus measurements, the glass transition temperature of the materials is near -90° C and appears to be relatively insensitive to the influence of sterilization. Furthermore, no basic differences in modulus behavior were noted, except that which could be expected from a decreasing S_A hardness.

Excellent foam structures were prepared from these elastomers employing the blowing agent VAZO. Preparative conditions involved exposure of the system for 20 to 30 min at 135° C during which the VAZO decomposed and the elastomer gelled sufficiently to top the developed foam structure. No loss of foam structure was noted during sterilization, but the foam became black.

An undesirable feature of the PBAA-MAPO elastomers is their poor tear properties. The emphasis of future development will be directed toward improved tensile properties by studying other crosslinking systems and prepolymers.

[1] PBAA, polybutadieneacylic acid polymer.

[2] MAPO, tri-imine (Interchemical Corp., Carlstadt, N. J.).

SPACECRAFT RELIABILITY (186-70)

PARTS RELIABILITY – SCREENING METHODOLOGY

NASA Work Unit 186-70-01-01-55
JPL 384-00401-2-3540
W. Bartel

OBJECTIVE

To support electronic subassembly advanced development such as Flight Sequences and Computer (186-68-02-08), DAS (186-58-06-07), and Communications (186-68-04-07) by developing improved screening methods for critical price parts including MOSFET, power transistors, silicon controlled rectifiers (SCR's) and resistors. This effort is divided into a number of subtasks as follows.

Development of MOSFET Reliability Test and Screening Methodology

This effort will develop test transistor methods and procedures for Metal Oxide Semiconductor Field Effect Transistors (MOSFET). This, a new device of anticipated major interest in CC&S and capsule electronics, features extremely high input impedance, low power, and high frequency operations. However, it is also extremely sensitive to transients encountered in testing and application. The effort will include a preliminary literature search and manufacturing conferences leading to definition of likely approaches. A contract entitled "MOSFET Reliability Test Methodology" will be let to develop and prove the most promising test methods in the amount of $28,000.

Samples of eight part types have been obtained. Preliminary inspection and measurements have been performed. Parts have been decanned for photomicrographing. A test procedure for an RFQ for the major effort has been written and is now in revision. Difficulties with adopting automatic test equipment to MOSFET parameters have been encountered and differing approaches are now being tried.

Development of Screening Methods for Secondary Breakdown in Power Transistors

It is tentatively planned to postpone this effort until FY 1967 and divert funding to a proposed method for screening resistors. The proposed method for resistors would provide a substantial cost and time saving through reduction in screening labor by about 90%. The method involves application of a power pulse of about five seconds while monitoring variation of resistance. Current screening methods include temperature cycles, TC measurements, and burn-in. If feasible, the method would result in savings of screening costs on the order of $100,000 annually.

An unsolicited proposal covering this is being reviewed and if acceptable, procurement action will be initiated in January 1966.

Development Screening Methods for Silicon Controlled Rectifiers

Establish a fast, accurate, and nondestructive test method for screening out potential failures from Silicon Controlled Rectifiers (SCR). The effort will attempt to establish correlation between RFI generation and junction anomalies with rectified current waveform. Due to manpower conflict in support of Voyager and Surveyor projects, no effort has been applied to this subtask to date. During the next quarter, preliminary analysis will be made of shot, thermal, and 1/f (bulk noise) under various operating modes. Based on the analysis, a contract will be initiated in the fourth quarter to correlate noise characteristics with potential early failures.

Investigation of Transistor Back Bias Versus Power Life Test

To determine the effectiveness of back bias at elevated temperature, in comparison to the currently used power life test. A voltage-temperature matrix test has been designed to provide comparative data for the two operating modes as well as data on the effects of temperature and voltage.

A contract for the investigation was let to Preston Scientific on December 16, 1965, for $13,960. The parts (750 units) have been prescreened at JPL and delivered to the contractor. The contractor is currently preparing for the laboratory effort. Completion is estimated at June 1966.

LONG LIFE STUDIES

NASA Work Unit No. 186-70-01-05-55
JPL 384-00501-2-3540

L. W. Wright
W. Bartel

OBJECTIVE:

Examine the behavior patterns of electric parts during life test and investigate methods for prediction of part parameter values and part failure rates after as much as 7500 hr operation. These predictions shall be based on early life characteristics. A secondary objective is to investigate part failure modes as a function of time and stress.

ACTIVITIES DURING REPORT PERIOD:

1. Transistor Screening Evaluation Test Program

Contract 950862 covering performance of this effort has been terminated. The termination action was initiated following several lengthy delays encountered in this program due to repeated extension of delivery dates for the test samples. It appeared that these delays would prevent a timely test completion and could jeopardize the entire purpose of the test. Dependent on the outcome of other tests currently being performed, it may be desirable to reactivate this program or a similar one at a future date.

2. Diode Screening Evaluation Program

Contract 950863 has been modified to extend the test duration from 5000 to 10,000 hr. The test extension cost an additional $10,889 increasing the total contracted amount to $38,885. The test is progressing satisfactorily and has completed in excess of 5000 hr life. An interim report covering the first 5000 hr of testing will be issued during the third quarter of FY 1966.

3. Resistor Screening Evaluation Program

Contract 950869 has been modified to extend the test duration from 5000 to 10,000 hr. The test extension cost an additional $5,624 increasing the total contracted amount to $15,806. The test is progressing satisfactorily and has completed in excess of 5000 hr life. An interim report covering the first 5000 hr of testing will be issued during the third quarter of FY 1966.

4. Accelerated Life Test Program for NPN Planar Transistors

Purchase Order M-382143 for $4,990 has been issued to fund a study of transistor thermal impedance preliminary to initiation of the main accelerated test program. This study will select from several alternatives the most accurate and repeatable method of thermal impedance measurement for the particular device type which will undergo accelerated testing. A final report covering this preliminary study will be available early in the third quarter.

Bids have been received to perform the main accelerated test program in accordance with Test Procedure No. 742.10-18. Bid review and negotiation is complete and it is estimated that a contract will be finalized furing January 1966.

5. Statistical Study to Support Item 4

A requisition to fund this effort has been prepared and forwarded to the Procurement Division. No actual progress, however, can be made on this effort until the main accelerated test program has been initiated.

6. Capacitor Screening Evaluation Test (FY 1964 and FY 1965 Funding)

Contract 950864 to perform a 5000-hr life test per Test Procedure 152.20-01 was funded during FY 1964. During FY 1965, additional funds were provided to extend the test from 5000 to 10,000 hr. The test was completed during the second quarter of FY 1966. No catastrophic failures were observed throughout the entire program. The test data is now being analyzed to determine parametric behavior during the 10,000-hr operating period. A final report on this program will be available during the third quarter of FY 1966.

7. Capacitor Matrix Test (FY 1965 Funding)

This test program covered by Contract 951125 has been completed and the test contractor is preparing all data and parts for shipment to JPL. Computer programs are being prepared for utilization in analyzing the difference in parameter degradation between the various stress levels. The data analysis will have been completed and a final report will be available during the fourth quarter of FY 1966.

8. Diode Comparative Screening Test (FY 1965 Funding)

In October 1965, Preston Scientific of Anaheim, California, was awarded fixed price Contract 951367 for $18,646 to perform this test per Test Procedure 741.00-03. The test is progressing satisfactorily and all steps through initial measurement have been completed. The diodes are now being subjected to nine different electrical/thermal screening stresses. Following this, all groups of a given diode type will then be subjected to identical life test conditions. The resulting data will allow establishment of relationships between the response of each group to the initial stress and the subsequent life test behavior. Comparisons of parameter stability and reliability during life test will be made between groups.

9. Radiation Thermal-Vacuum Study

Future space vehicles utilizing nuclear-electric propulsion must be provided with adequate shielding to protect the electronics from neutron and gamma radiation. These vehicles will be required to operate for prolonged periods of time and consequently, the radiation exposure rate on the electronics must be maintained at a sufficiently low level such that the performance and reliability of the circuit elements are not significantly degraded. From previous experimental information, it appeared feasible that electronic parts would operate for 10,000 hr at the following levels of radiation:

Item	Dose rate	Total dose
Fast neutrons	$3 \times 10^5 n/cm^2/sec$	$10^{13} n/cm^2$
Gamma rays	10^5 ergs/g(c)/hr	10^9 ergs/g(c)
Temperature	100 °C	

The radiation thermal-vacuum effects study was designed to quantitatively assess the performance characteristics of typical standard parts used in current spacecraft electronics and to assess the reliability of these parts in various combinations of the above environments.

The radiation thermal-vacuum effects study has been completed through an additional 4,000 hr of testing with electrical parameter measurements having been completed at the 6,000-, 7,000-, 8,000-, and 9,000-hr measurement points. Data cards from parameter measurements have been converted through and including the 8,000-hr measurement point to format requirements of JPL Specification ZPP-2090-GEN and have been received by JPL. Data has been processed and reduced into the form of computed statistics sheets in accordance with JPL Specification ZPP-2040-GEN through and including the 7,000 hr measurements. Preliminary analysis of results for monitoring purposes was completed with listings of failures reviewed and physical analysis of a sample quantity completed. Significant publications have included the tenth and eleventh quarterly progress reports which were prepared by the contractor. Contractual activity included the negotiation for a change in the edit program with CEIR for $250.00. Total cost for data reduction is now $7,896. The contract with Battelle Memorial Institute was modified extending the delivery schedule for the final report to April 1966 and increasing the funds by $5,000. The total cost for the radiation test program is now $249,020.00.

During the next report period, the radiation exposures and operational life, tests will continue until February 1, 1966, when 9,700 + hr of testing have been completed. The AEC has ordered a shutdown of the reactor at that time and the test will be terminated. Final measurements will subsequently be taken and data will be converted and processed. Since the data reduction thus far completed has shown that difficulties in the test program exist in certain areas, a more detailed approach is necessary to study the effects and relationships in certain semiconductors. For this purpose, additional data presentations will be implemented at an estimated cost of $5,000. Final analysis of all the experimental data will be accomplished in February and March 1966 with the final report being published in June.

FAILURE MECHANISMS

NASA Work Unit No. 186-70-01-07-55
JPL 384-00701-2-3540
L. W. Wright

OBJECTIVE

Effect an improvement in the reliability of critical electronic parts by:

1. Determining the most likely causes of incipient microcracks in semiconductor devices, the relation of these cracks to long-term reliability, and methods by which these cracks can be detected and/or eliminated.

2. Establishing more positive techniques for the physical characterization of electronic parts.

ACTIVITIES DURING REPORT PERIOD

1. Contract to Study Semiconductor Microcracks

No progress to date due to lack of manpower.

2. Part Physical Characterization Studies

No progress to date due to lack of manpower.

3. Contract to Study Package Gases

No progress to date due to lack of manpower.

4. Develop a Bond Strength Tester

No progress to date due to lack of manpower.

5. Contractor Engineering Support

The funds intended for contractor engineering support will be redirected to cover JPL engineering direct labor costs. Efforts are being made to hire engineers rather than obtain contractor support.

6. X-Radiation Effects Test (FY 1965 Funding)

In December 1965, the Boeing Company of Huntsville, Alabama, was awarded fixed price Contract 951369 for $37,900 to perform this test per Test Procedures 742.10-17 and 742.20-04. Testing is expected to commence early in the third quarter of FY 1966. These tests have been designed to investigate degradation effects which may be produced by radiographic inspection of semiconductor devices.

7. Parameter Distribution Study (FY 1965 Funding)

Satisfactory bids for the data necessary to this study have been received from manufacturers of glass capacitors, ceramic capacitors, and carbon film resistors. Purchase Orders have been written to obtain this data. No suitable bids have yet been received for data on either transistors or diodes. The capacitor and resistor data will be received during the third quarter of FY 1966.

SPACECRAFT TESTING EQUIPMENT AND TECHNIQUES (186-71)

ADVANCED SOLAR SIMULATION DEVELOPMENT
NASA Work Unit 186-71-01-01-55
JPL 384-10101-2-3750
R. E. Bartera

OBJECTIVE

The long-range objective of this unit is to improve solar simulation capabilities in anticipation of flight project requirements by the development of new systems and more efficient components.

10-ft SPACE SIMULATOR

Arising out of development accomplished under this work unit in previous years, a solar simulation system had been designed, fabricated, and incorporated in JPL's new 10-ft space simulator with C of F funding. During the first half of FY 1966 that system underwent a complete calibration with the following favorable results:

Beam Diameter	8 ft	
Intensity	up to 160 w/ft^2	
Field angle (apparent Sun diameter)	3° ($\pm$ 1 1/2°)	
Uniformity	±5% (no steep local gradients)	
Spectrum (approx. xenon)		
<4250Å	10%	as measured
4250Å to 7500Å	39%	with spectrophotometer
>7500Å	51%	

During the calibration, which was funded by the *Surveyor* Project, assistance was given under this work unit in the resolution of several problems and apparent system deficiencies, especially in uniformity and intensity. The 10-ft space simulator is now being used for thermal testing of *Surveyor* spacecraft.

25-ft SPACE SIMULATOR

Assistance continued to be given on a consultation basis to the design team responsible for designing and fabricating the 15-ft solar system for the 25-ft space simulator modification now in construction. During the fiscal year, it became obvious after consultation with vendors that the application of a nickel surface (for optical polishing) to the 23-ft-diameter collimating mirror was beyond the state of the art and required a development program properly falling under this work unit. After allocation of appropriate funds, a contract was let to advance the technology and is progressing satisfactorily.

HIGH POWER ARC LAMPS

Investigation of 20-kw xenon compact arc lamps has not progressed as rapidly as had been hoped. We have experienced eight lamp failures out of nine attempts; the lamps were replaced by the manufacturer at no dollar cost but considerable time loss. The one lamp which survived more than 10 hr operated well for 400 hr with only about 10% reduction in performance. The results of that experiment indicate that it will be possible to reduce the solar field angle in the 25-ft space simulator to 2 deg (dia) if a reliable lamp configuration can be obtained.

The 26-in.-diameter prolate ellipsoidal collecting reflector procured for use with the 20-kw lamps has performed very well and no problems were encountered.

ALBEDO

No work was accomplished under this work unit on simulation of planetary albedo and radiation. Previous years' results have been used by others in the preparation of a C of F Preliminary Engineering Report. Since we do not now anticipate a requirement for such a simulator at JPL, this effort will be deleted from this work unit.

FUTURE ACTIVITIES PLANNED

We now have on hand three 20-kw lamps of supposedly improved configuration; we will investigate and evaluate them primarily for life/reliability characteristics.

We anticipate a spacecraft testing requirement for a solar beam with significantly better field angle/intensity/spectral performance. To significantly affect these parameters it is necessary to increase the amount of net available energy which is primarily a direct function of the source (lamp arc) brightness. We will therefore reinstitute a program suspended two years ago which was aimed at increasing that brightness. Quantitative information on the effects of such parameters as magnetic fields, pressure, electrode temperature, and electron temperature will be obtained using both the versatile laboratory arc lamp (Variarc) which has been previously designed and commercially available lamps.

ADVANCED STUDIES (684)

PLANETARY AND INTERPLANETARY (684-30)

ADVANCED TECHNICAL STUDIES (IN-HOUSE)
NASA Work Unit 684-30-01-10-55
JPL 388-3xxxx-x-xxxx

J. E. Long
T. A. Barber
K. H. Fishback

ADVANCED PLANETARY PROBE – J. E. Long - Study Leader

Study Objective

1. Evaluate and establish magnitude of mission development and technology required for "first-step" flyby missions of the outer planets (Jupiter flyby taken as focus mission).
2. Evaluate and mechanize to the greatest extent possible the science objectives of EPD-280, "Jupiter Advanced Planetary Probe Science Objectives and Typical Experiments."
3. Develop and evaluate in depth several system mechanizations representative of various approaches and interpretations of a minimum mission. Consideration to be given to "growth" from the sense of additional experiment sophistication and adaptability to planetary targets other than Jupiter.
4. Summarize tradeoffs of the several mechanizations and recommend, if possible, the system approach most compatible with the overall study objectives.
5. Identify major advanced development tasks required to realize mission feasibility.

Study Progress and Status

To evaluate various "families" of system concepts for applicability to the minimum mission requirement, four mechanizations are being developed to the greatest depth possible.

1. Active Sun-orientation with random orientation roll hold or rate limitation.
2. Spin stabilization to Sun orientation.
3. Active Sun-orientation with roll reference.
4. Spin stabilization with Earth orientation.

Detail subsystem analyses and development of the first three configurations are in process. Reports on these analyses and tradeoffs will be made to the study committee during the months of January and February and will provide the basis for the evaluation of the system concepts for suitability to the "minimum mission" mechanization.

Due to time and resource constraints, the Earth-orientation system approach will not be analyzed in depth. Development of this system approach is the subject of a contracted study to be performed by TRW Systems Group in the near future. Analyses of this system approach during the current study will be restricted to general system considerations related to the mission requirements and design parameters common to the other system approaches.

Subsystem analyses reported to date on power requirements and thermal control considerations have indicated the particular suitability of RTG power sources to the mission. In both areas the major factor favoring the RTG is its relative immunity to the large variation in solar constant during the mission. As a result of this rather strong preference, analyses concerning the compatibility of science instrumentation with RTG radiation spectrum have been made and design criteria for instrument/source separation and shielding have been developed and reflected in configurations for the three system approaches. Confirmation of this criteria is a major development area to be identified for further study and development.

Concurrent with subsystem analyses and reporting, mission requirements pertinent to realistic evaluation of the various system concepts' suitability are being analyzed and reported. The general categories of these mission analyses are:

1. Evaluation of environmental factors and protection requirements with emphasis on (a) micro-meteoroid hazard, (b) trapped radiation hazards at Jupiter, and (c) effects of intense magnetic fields at Jupiter.

2. Trajectory analysis of the 1974-1979 opportunities to supplement 1970-1973 analyses previously accomplished. This analysis will include trajectory correction requirements for planetary targeting for the various system approaches.

3. Definition of preliminary mission objectives and "worth," and analysis of mission time effects on accomplishment of these objectives. Particular emphasis will be placed on the mechanization and redundancy required as a function of mission life.

4. Analysis of encounter science instrumentation requirements (view angle, weight, etc.) as a function of flyby distance. Through this consideration the effects of a particular experiment on targeting and spacecraft mechanization can be assessed.

5. Analysis of program cost as a function of system approach, mission objectives, and flight time.

The culmination of the subsystem and mission analyses will be a realistic definition of mission requirements and the system approach most suitable to these requirements. From this result it will be possible to identify the major development tasks required to achieve program feasibility.

RETRO LANDER STUDY — T. A. Barber - Study Leader

Scope of Study

Initially, the study was intended by the Advanced Technical Studies (ATS) office to be a general parametric design of Mars retro propulsion spacecraft. However, at the beginning of the second fiscal quarter 1966, increased interest in the Voyager Project forced a realignment of study goals. The study became a short-duration, high-intensity effort which was directed towards the conceptual design of a single capsule configuration. Since little study effort had preceeded this change, the major portion of the work has been aligned to the conceptual design. Thus, the study became much more narrow in scope due to the project desire for a particular, definite answer.

The objectives of the study were to:

1. Assess the retro landing mode in terms of its technological feasibility.

2. Calculate the payload capability of the retro landing system.

3. Develop a feasible control technique.

4. Develop a sequence of events which are characteristic of the retro lander.

5. Show a single conceptual design which is feasible in terms of a 1971 launch date.

Study Tools Developed

Although the prime goal was to arrive at a single design which would suffice, the very nature of the technical problem required preliminary optimization to arrive at the proper initial capsule sizing. Since the aeroshell weight is a function of the desired terminal velocity and the retro propulsion system weight is a function of the same velocity, the optimization involved a weight trade between the aeroshell and the retro propulsion system.

In order to perform the optimization, both the aeroshell weight and the propulsion system weight were developed as a function of the terminal velocity desired. Thus, the first two study tools were the parametric description of the aeroshell weight and the propulsion system weight.

In order to use the above parametric data, trajectory runs for both the ballistic descent and the retro propulsion descent were made for the same parametric values. Comparable values were thus combined by an optimization program, and the set of values which resulted in the greatest performance (lowest combined aeroshell-propulsion weight) were used as the starting point for the lander design.

A summary of the study tools developed is:

1. Aeroshell weight as a function of ballistic coefficient diameter, gross weight, and acceleration.

2. Propulsion system weight as a function of required retro velocity and thrust-to-weight ratio.

3. A ballistic trajectory program to derive inputs for (1).

4. A powered flight trajectory program to derive inputs for (2).

5. An optimization program to combine (1) and (2) - to arrive at the maximum and payload performance point.

6. A digital computer program to assess the control requirements and effects of radar noise on the lander guidance system.

7. An analog computer program to assess the dynamic stability and stabilization of the retro landing system.

The weights of the various required subsystems and scientific payload were tabulated, and total lander weight was derived from the resulting gross payload weight. Due to the extremely short study schedule, conservative values were adopted in all areas, and the total weight which was derived represents an upper bound on the actual design. In spite of the conservatism, certain retro propulsion configurations permit significant payload to be landed on the Mars surface. These configurations have gross weight and diameters which are compatible with existing or programmed boost vehicles.

Results

The results of the study are:

1. A feasible retro lander conceptual design.

2. The study tools described in Section II.

3. A clear need to study further to resolve the questions raised during the short study.

Recommendations for Further Study

Because of the short duration of the study, it was not possible to answer certain feasibility questions, and further study should be done in order to fully qualify the statement in Results (1). The major open subsystem area is the radar altimeter and range and velocity sensor. In addition, effort should be directed to better defining the weight and other interface requirements of the remaining landed subsystems.

On a larger scope, it would be reasonable to remove the programmatic and parametric restrictions characteristic of the 1971 launch, and perform the originally intended parametric study of the retro lander.

Since the retro propulsion mode is the only real contender for landing large payloads on an extraterrestrial body with low atmospheric density, it seems desirable to have continuing study supported.

HIGH ENERGY MISSIONS-ADVANCED PLANETARY PROBE — K. H. Fishback

Objectives

The objectives of this study program are to conduct a conceptual design and feasibility study to develop first-generation spacecraft concepts adaptable for long-range, long-duration planetary missions in the region extending from Mars to increasing greater distances from the Sun. The study shall include the conceptual design of spacecraft systems to accomplish basic flyby missions of the planets Jupiter, Saturn, and Pluto. In addition, the study will examine the growth potential of the basic concepts through the use of modular design concepts to perform orbiter and planetary capsule entry missions. In accordance with these mission objectives the study is expected to: (1) establish the requirements of the mission in terms of mission objectives and capability and resources required for mission accomplishment and (2) evolve appropriate spacecraft system conceptual designs.

The mission study includes the selection of mission and scientific objectives, which vary in complexity to provide sufficient flexibility for future project experiment selection. A scientific payload complement will be selected relative to each planetary mission, and spacecraft conceptual design from the following broad science objectives of the study:

1. Measurement of the spatial distribution of interplanetary particles and fields.
2. Measurement of the salient features of planetary atmospheres with particular emphasis upon remote measurements from a flyby spacecraft.
3. Observations of the planets, i. e., visual, infrared, etc.

Science payloads will be configured by the study contractor on the basis of JPL broad objectives relative to each spacecraft conceptual design capability and will be concurred on by JPL in the initial phase of study.

Spacecraft conceptual and mission designs will be established in view of these objectives by: (1) establishing the functional requirements associated with each objective, (2) forecasting the applicable state of the art, (3) synthesizing system concept, and (4) reviewing these system concepts in terms of appropriate spacecraft systems.

During the previous report period several technical discussions were held with Thompson-Ramo-Wooldridge Corporation, as a result of their previous unsolicited proposal study evaluation by JPL, an RFP was initiated on June 29, 1965, to TRW. Due to budget limitations at that time, the proposal was requested in two parts. Part 1 was a proposal which would meet the full intent of JPL's conceptual design study scope of work. Part 2 was a delection of all work task not germane to the technical scope of the study, i.e., management data.

Study proposals in response to the RFP were received from TRW on August 1, 1965, and August 10, 1965. Subsequent to proposal evaluations, a request to NASA/OSSA was made to start contract negotiations with TRW for the study. On

September 28, 1965, approval was received. Following receipt of approval a technical meeting was held with TRW to ascertain the merit in some detail for including addendum items to the basic scope of work. It was determined that sufficient substance in three items warranted inclusion. These were: Cost Effectiveness, Costing, and Development Programs Schedules. On October 14, 15 contract negotiations were held at TRW at which time the Statement of Work was reviewed and minor revisions made. The contract was negotiated on the basis of a CPFF Level of Effort contract for an estimated cost of $154,653.00.

During the course of study planning and negotiations a forecast of launch vehicle capability for the time period of mission accomplishment was recognized to be an essential study input. A launch vehicle guideline document was generated to cover the potential growth and future operational status of existing vehicles. This guideline for launch vehicles will be used as a basis for conducting this study. Launch vehicle options given by this guide include:

1. Saturn V/Centaur.
2. Saturn V.
3. Saturn IB/Centaur/HEKS.
4. Titan IIIC/Centaur.
5. Atlas SLV3X/Centaur/HEKS.
6. Atlas SLV3X/Centaur.

Launch energy capability of these vehicles with the exception of Atlas SLV3X/Centaur provide sufficient capability in combination with spacecraft design selection for exploration to Pluto distances and allow flexibility in design for choice of program cost, time of flight, reliability, etc.

Contract approval was received on December 29, 1965, and TRW was instructed to begin study. The term of study will be 6-1/2 months with a mid-term progress report due at the end of March 1966, and a final progress report due at the end of June, 1966. Each progress report is to be followed by an oral review at the JPL.

The Statement of Work with minor revisions resulting from contract negotiations is as follows:

<u>Statement of Work No. 1311</u>

I. INTRODUCTION:

The objective of this study program is to conduct a conceptual design and feasibility study to develop first-generation spacecraft concepts adaptable for long-range, long-duration planetary missions in the region extending from Mars to increasing greater distances from the Sun. The study shall include the conceptual design of spacecraft systems to accomplish the following: (1) basic flyby missions of the planets Jupiter, Saturn, and Pluto, and (2) examination of the growth potential of the basic concepts through the use of a modular design

concept to perform orbiter and planetary capsule entry missions. Particular emphasis is placed upon the spacecraft design tradeoff analysis leading to configuration optimization for a range of injection weights which would have the highest probability of mission accomplishment with the following scientific objectives:

(a) Measurement of the spatial distribution of interplanetary and planetary particles and fields.

(b) Measurement of the salient features of planetary atmospheres, with particular emphasis upon remote measurements from a flyby spacecraft.

(c) Observations of the planets, i. e. , visual, infrared, etc.

II. SCOPE OF WORK:

(a) In the performance of this study, the contractor shall:

(1) Develop spacecraft system conceptual designs to meet the objectives stated above by accomplishing the following:

(i) Establish the functional requirements for spacecraft systems to perform the mission.

(ii) Forecast the applicable state of the art for the time period considered.

(iii) Perform design tradeoffs as a basis for the rationale employed for design selections.

(iv) Synthesize the appropriate system concepts.

(v) Identify the problem areas and indicate approaches to their solution.

(vi) Review the system concepts in terms of the Mariner Mars '64 and IQSY Pioneer Spacecraft System Designs.

(2) Provide a description for each of the systems developed under paragraph (a) (1) above which shall include, but not necessarily be limited to, the following:

(i) System block diagrams

(ii) Operational sequences

(iii) Weight and power estimates

(iv) System pointing accuracies and orientation maneuvers.

(v) Spacecraft and science experiment internal-external interface compatibilities, including radioisotope thermoelectric generator radiation and thermal effects.

(vi) Redundancy considerations for increased reliability.

(vii) Evaluation of the design variations required for each of the scientific objectives showing the design complexities involved.

(viii) Spacecraft conceptual configurations and launch vehicle(s) general mechanical compatibility.

(ix) Optimization of the spacecraft systems developed in (a) (1) with the launch vehicle choices showing tradeoffs involved.

(3) Provide descriptions of the subsystem designs studied and the mechanization approaches to be employed. This shall include, but not necessarily be limited to:

(i) Means by which subsystem designs meet the system, or functional requirements of (a) (1).

(ii) The design tradeoffs considered and the rationale used for design selection.

(iii) The life time reliability design considerations.

(iv) Identification of the problem areas determined and approaches to their solution.

(4) Investigate spacecraft modular concepts which would provide orbiter and capsule entry capabilities to the basic flyby design for potential growth of the system. This shall include, but is not limited to:

(i) The mechanization feasibility and spacecraft interface compatibility.

(ii) The operational feasibility and basic spacecraft optimality considerations.

(iii) Modifications required to the basic spacecraft to utilize the modular concepts.

(5) Conduct a reliability analysis for systems selected which shall include, but is not limited to:

(i) Long life time missions to the outer planets.

(ii) System/subsystem reliability assessments.

(iii) Reliability improvement techniques.

(iv) System failure mode analysis to establish probabilities of mission and partial mission successes.

(6) Perform a cost/effectiveness analysis for the selected spacecraft system(s) and launch vehicle(s) combinations to accomplish the intended mission objectives. The basis of the analysis shall be stated.

(7) Prepare preliminary estimates of schedule and cost for those system(s) developed under paragraph (a) (1) above. Major variations in cost and schedule shall be noted. The cost estimates shall be in the same format as the costing categories for the Mariner Mars 64.

HIGH ENERGY MISSIONS-JUPITER FLYBY – K. H. Fishback

Objectives

The objective of this study is the examination of spacecraft system design concepts for first generation flyby missions of the planet Jupiter in the time period 1973-80. The study is expected to: (1) establish the requirements for missions in terms of mission objectives, and the capabilities and recourses required for mission accomplishment, and (2) the generation of appropriate spacecraft system conceptual designs.

In order that these objectives be carried out, the study will establish scientific payloads commensurate with the conceptual designs and in consonance with the following broad science objectives of the study:

1. Interplanetary and planetary measurements of the spatial distribution of particles and fields. Measurements shall include but not necessarily be limited to:

   (a) Magnetic fields
   (b) Solar plasma
   (c) Dust and micrometeorites
   (d) Ionized radiation

   The trapped radiation belts of Jupiter are considered a special case of particle measurements and shall be presented relative to the design complexity required for their measurement.

2. Measurements of the planetary atmosphere of Jupiter which shall include but not necessarily be limited to:

   (a) Composition
   (b) Temperature and pressure

3. Measurements of the physical properties of Jupiter which shall include but not necessarily be limited to:

   (a) Observation of the cloud cover and possibly gross features of the Jovian terrain.

The contractor and JPL will concur upon the science complement of each conceptual design in the early phase of the study.

The alternate means of accomplishing the set of mission objectives will be studied by: (1) establishing the functional requirements associated with these objectives, (2) forecasting the applicable state of the art, (3) synthesizing system concepts, and (4) reviewing these system concepts in terms of appropriate current spacecraft system design.

During the close of the last semi-annual report period and RFP was submitte to 17 companies. On July 6, 1965, proposals were received in response to the RFP from six contractors. Subsequent to the receipt of the proposals, an evaluation was made by JPL and a contractor selected. On August 2, 1965, a request was made to NASA/OSSA for approval to negotiate a study contract with General Dynamics/Fort Worth relative to their study plan. A study plan, Fig. 1, and a study schedule, Fig. 2, were presented at this meeting. The study tasks were discussed in some length relative to study depth and emphasis. In particular a tentative list of three scientific payload on November 17, 1965.

On December 1, 1965, discussions were held with General Dynamics in Fort Worth relative to their study plan. A study plan, Fig. 1 and a study schedule, Fig. 2 was presented at this meeting. The study tasks were discussed in some length relative to study depth and emphasis. In particular, a tentative list of three scientific payload packages were presented for JPL's comment. Launch vehicle options and range of spacecraft weights to be considered in the study were discussed. A launch vehicle guideline document generated by JPL was presented. On the basis of these discussions it appears that the study will evolve a range of spacecraft concepts whose weight will be compatible with injection energies which vary from an Atlas SLV3X/ Centaur to a Saturn V/Centaur launch vehicle combination.

On December 15, 1965, the first monthly study report was received from the contractor which covered study activity through November. The contractor's progres to that date was:

1. A detailed study plan was submitted to JPL in accordance with the study contract.

2. Earth-Jupiter trajectory data for eccentric transfer orbits covering the applicable launch periods in 1973-1980 were generated and incorporated in format suitable for mission planning.

3. Groups of instruments for scientific investigation which constitute minimal intermediate and full science capability were determined.

Plans for future activity during the next monthly report period were:

1. Description of each of the potential scientific instruments will be completed in sufficient detail to allow design of the supporting subsystems.

2. A decision on which launch vehicles will be considered in the study will be made - this decision will be based on launch vehicle data supplied by JPL as guideline information.

3. Preliminary decisions as to the subsystem concepts which will comprise the minimal spacecraft will be made.

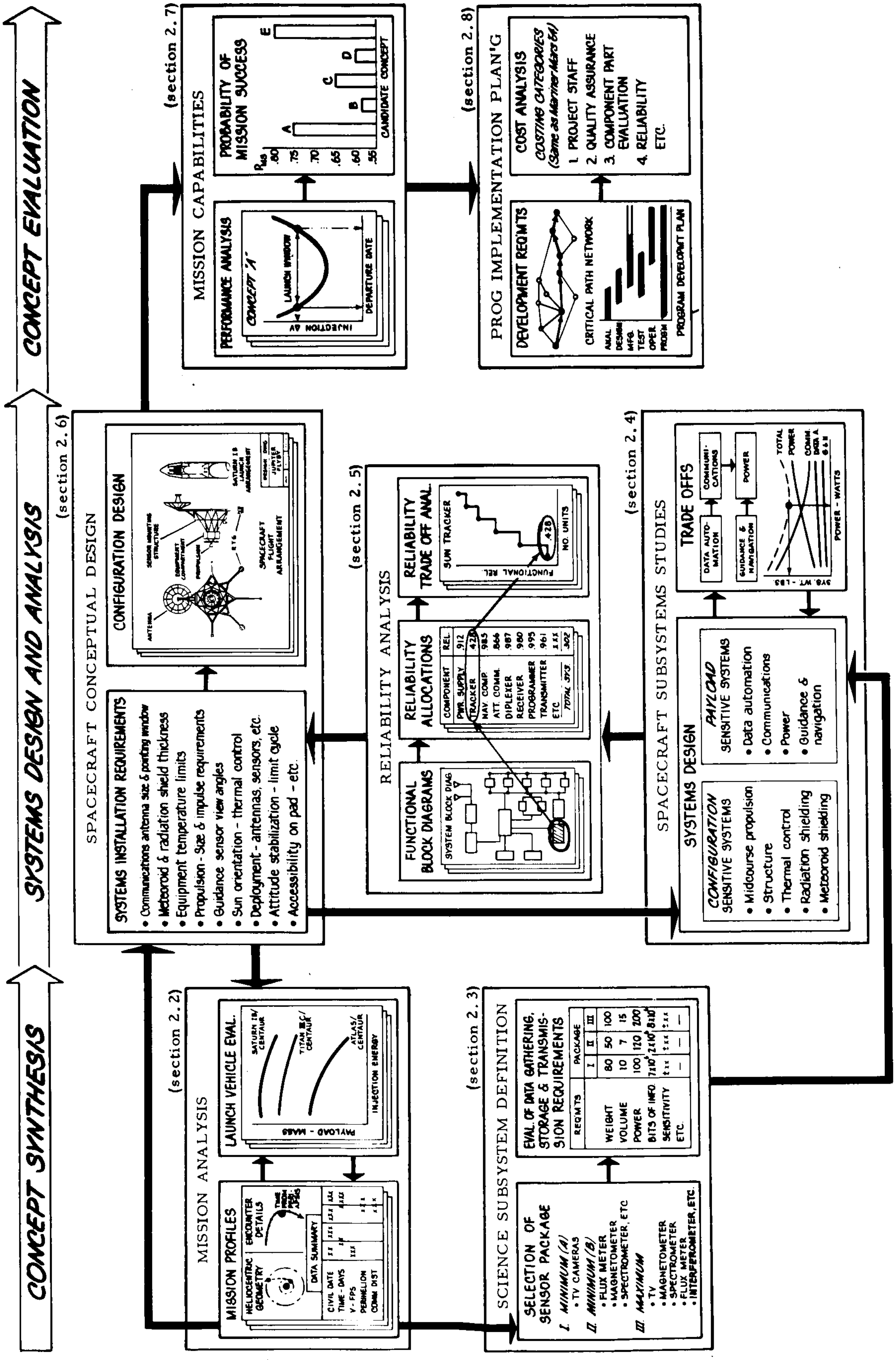


Fig. 1. Study plan

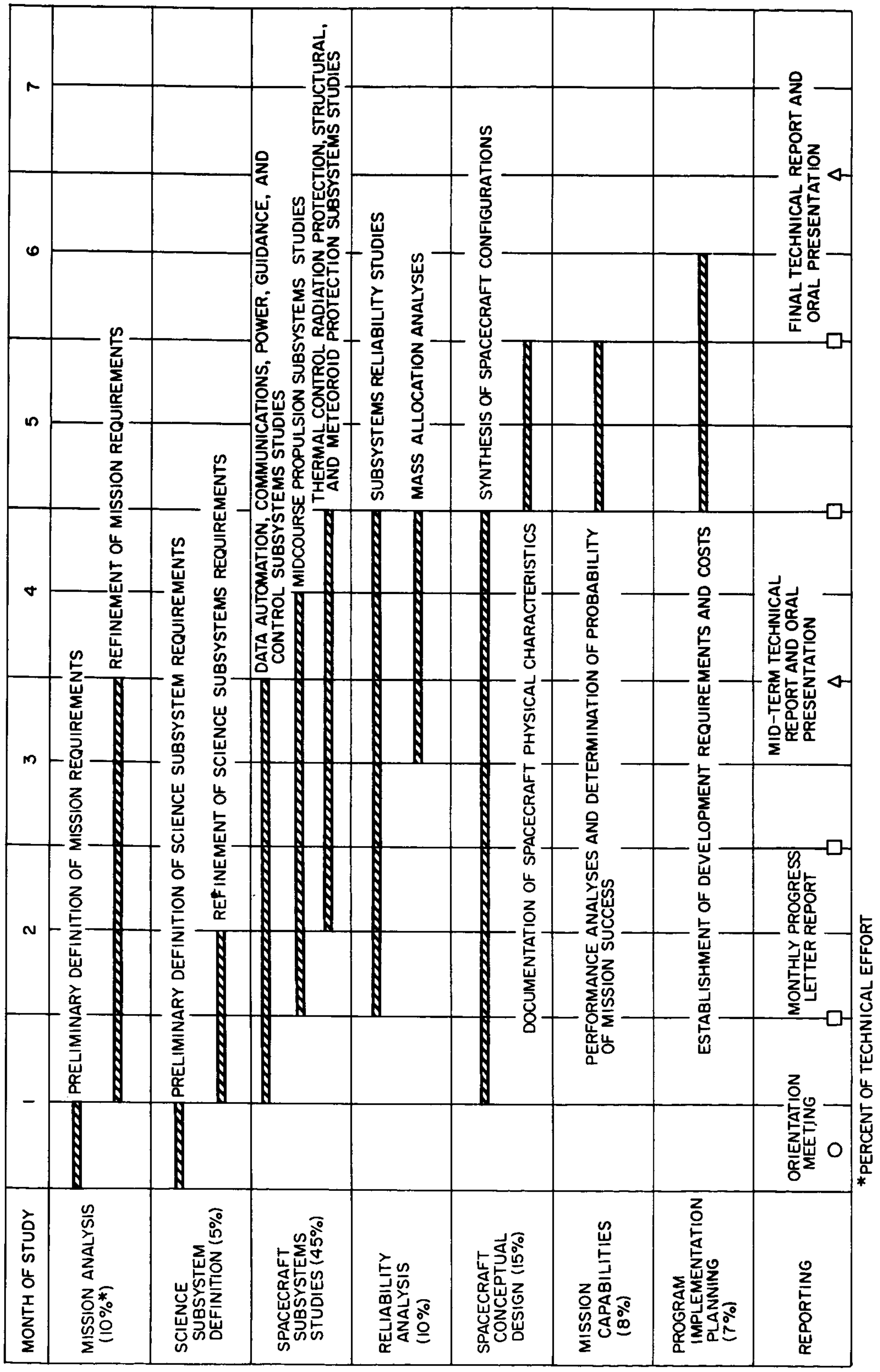


Fig. 2. Study schedule

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ALTERNATE MARS STUDY CONTRACT
NASA Work Unit 684-30-01-11-55
JPL 388-3xxxx-2-1600

The study contract planned in this work unit was transferred to Voyager Project Office cognizance in October, 1965, by agreement between JPL and OSSA-SL, and this work unit was cancelled.

A small in-house study on a possible Mars retro lander was performed and is reported in Work Unit 684-30-01-10-55, Retro Lander Study.

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ADVANCED PLANETARY PROBE STUDY CONTRACT
NASA Work Unit 684-30-01-12-55
JPL 388-3xxxx-x-xxxx
P. N. Haurlan

No effort has as yet been expended on this work unit.

The plan is to submit an RFP to industry during the last quarter of FY 1966 to perform a conceptual design study of a "preferred" Advanced Planetary Probe (Jupiter) concept. This "preferred" concept will be selected and defined as an output of the current in-house Advanced Planetary Probe study. Refer to NASA work unit 684-30-01-10 for a technical discussion of the concepts under consideration.

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VENUS FLYBY STUDY CONTRACT
NASA Work Unit 684-30-01-13-55
JPL 388-3xxxx-x-xxxx
P. N. Haurlan

During the reporting period, the first draft of a document entitled "VENUS: Preliminary Science Objectives and Experiments for Use in Advanced Mission Studies" was published as Engineering Planning Document 328. This document provides the titled information for a potential Venus flyby with or without atmospheric probe mission to be launched by an Atlas Centaur launch vehicle.

During the second half of FY 1966, a Statement of Work for a contracted study of the above mission will be prepared with an RFP scheduled to be submitted to industry early in the last quarter of the year.

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Part B
Physics and Astronomy

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ADVANCED STUDIES (684)

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MAGNETODYNAMICS IN SPACE (188-36)

MAGNETIC PHENOMENA

NASA Work Unit 188-36-01-01-55
JPL 385-60101-2-3280
E. J. Smith

OBJECTIVE

The objective of this task is to investigate naturally occurring extremely low-frequency (3 - 3000 cps) magnetic field variations generated within, or above, the ionosphere; to study their origin, modes of propagation, association with solar-terrestrial phenomena, and dependence on magnetospheric-ionospheric parameters; and to utilize experimental techniques for the detection and analysis of signals observed at the Earth's surface which may be applicable to flight experiments.

SIMULTANEOUS SATELLITE AND EARTH-BASED MEASUREMENTS

One of the primary objectives of this program has been to obtain extremely low-frequency (ELF) data above the ionosphere so that it may be compared with simultaneous measurements made at the Earth's surface. OGO-2, launched in October, contains a search coil magnetometer experiment designed to detect and record magnetic field variations in the frequency range from 0.01 to 1000 cps. Since the launch, simultaneous recordings have been made at a remote field site located above the San Gabriel dam when OGO-2 was within 45 deg of the site in latitude and longitude. Variations at the Earth's surface (primarily in the frequency range from 3 to 300 cps) were detected by search coil sensors, amplified, and recorded on magnetic tape for subsequent analysis. Because the field site is not staffed continuously a programmer was designed, fabricated, and installed that turns the tape recorder on and off at the appropriate times using a punched paper tape input. Since the most useful form of the satellite data (namely the frequency components from 1 to 1000 cps) is transmitted in real time over the OGO Special Purpose Telemetry channel, arrangements were made to have Stanford University Electronics Research Laboratory record the ELF data along with their very-low-frequency (3000 to 30,000 cps) data. ERL has been recording the ELF signals on magnetic tape and shipping them to JPL for analysis. Thus, Earth-based and satellite data are available and comparisons of the simultaneous measurements are about to begin.

ANALYSIS OF GROUND-BASED MEASUREMENTS

A related aspect of the program, the recording and analysis of signals at the Earth's surface on a more regular schedule independent of the satellite status, has continued. Preliminary analysis of these data has shown, as anticipated, that daily variations in the average signal strength are correlated with thunderstorm activity. The study of the diurnal variation in the strength and direction of arrival of the signals has been extended by continuously monitoring the signal levels at the field site using averaging circuits and strip chart recorders. Plans have been formulated to look for "helium whistlers" (signals caused by lightning whose propagation along

magnetic field lines above the ionosphere is dependent on the presence of helium ions) using spectral analysis techniques.

JPL Technical Memorandum No. 33-272, Vol. I

ADVANCED MAGNETOMETER INSTRUMENTATION
NASA Work Unit 188-36-01-03-55
JPL 385-60401-x-3230 (FY-1966)

David D. Norris

OBJECTIVE

The objective of the magnetometer development program is to complete a second generation low-field vector helium magnetometer of inherent reliability and to extend development of the second-generation system to provide high-incremental resolution with wide dynamic range. To perform operational evaluations over temperature ranges compatible with lunar, cislunar, planetary, and interplanetary missions.

PROGRESS

Figure 1 shows the scheduled events for FY 1966. The three main efforts will be discussed separately.

Nonmagnetic Vacuum Testing Facility

The purpose of this portion of the task is to develop a vacuum facility in which magnetometer sensor offset measurements can be made over a wide temperature range. The vacuum rotating device and the rotational liquid nitrogen transfer mechanism have been fabricated and tested with satisfactory results and, at the present time, parts are being fabricated to complete the sensor-flipping mechanism. The design of the magnetic shield for the vacuum facility is complete, and a fabrication procurement has been initiated. The vacuum test facility development should stay on schedule as shown in Fig. I.

Spectral Studies

The purpose of this effort has been to establish a technique for measuring the pressure of helium lamps and cells after their fabrication. A series of spectra have been taken for helium lamps of various pressures, and, although the spectral intensities have varied with pressure, the relative intensities of the spectral lines in the helium glow discharge do not show appreciable pressure sensitivity. Further studies will be made of the available data, but to date the results have not been encouraging. Impurities may have a more significant effect on the spectral characteristics than have been anticipated; and this, coupled with other measurement variables, excludes the possibility of using absolute spectral intensity pressure calibrations.

Electronics Development and System Test

The electronics portion of the magnetometer system is complete, but we are deviating slightly from our previous schedule plan shown in Fig. 1 to redesign the electronics using integrated circuits which have recently become available. The use of the integrated circuits will eliminate approximately 150 active and passive electronics components. The use of these will effectively reduce the instrument's

weight. Another deviation from our plan shown on Fig. 1 occurred as a result of our proposal to put a magnetometer on the ALSEP. We wished to compare the operating characteristics of the fluxgate magnetometer with the helium magnetometer to determine which device was most suitable for that application. Preliminary thermal testing was performed on a fluxgate sensor in a temperature range from -150 to +150°C. During these tests, we found the fluxgate offset varied by approximately 2 gamma; however, the test results are of questionable accuracy because of thermal drift in the magnetic shield characteristics. The results were sufficiently encouraging, however, to continue this line of investigation. We proceeded to design and fabricate a set of electronics so that when our low-field vacuum facility is available, more detailed temperature offset studies could be made along with studies of the helium magnetometer. Some of this work was reported in SPS 37-36, Vol. IV. Even though our ALSEP proposal was not accepted, the fluxgate work that was done served two useful purposes

1. A comparative study will be made of the helium magnetometer and the fluxgate magnetometer when our facility is completed.

2. Slight modifications were made to the low-field fluxgate circuitry to allow its use in the geomagnetic field, and this modified circuit is being built at the present time for use as attitude information on Dr. MacDonald's balloon experiment.

Thermal-vacuum system testing should be completed as predicted in Fig. 1.

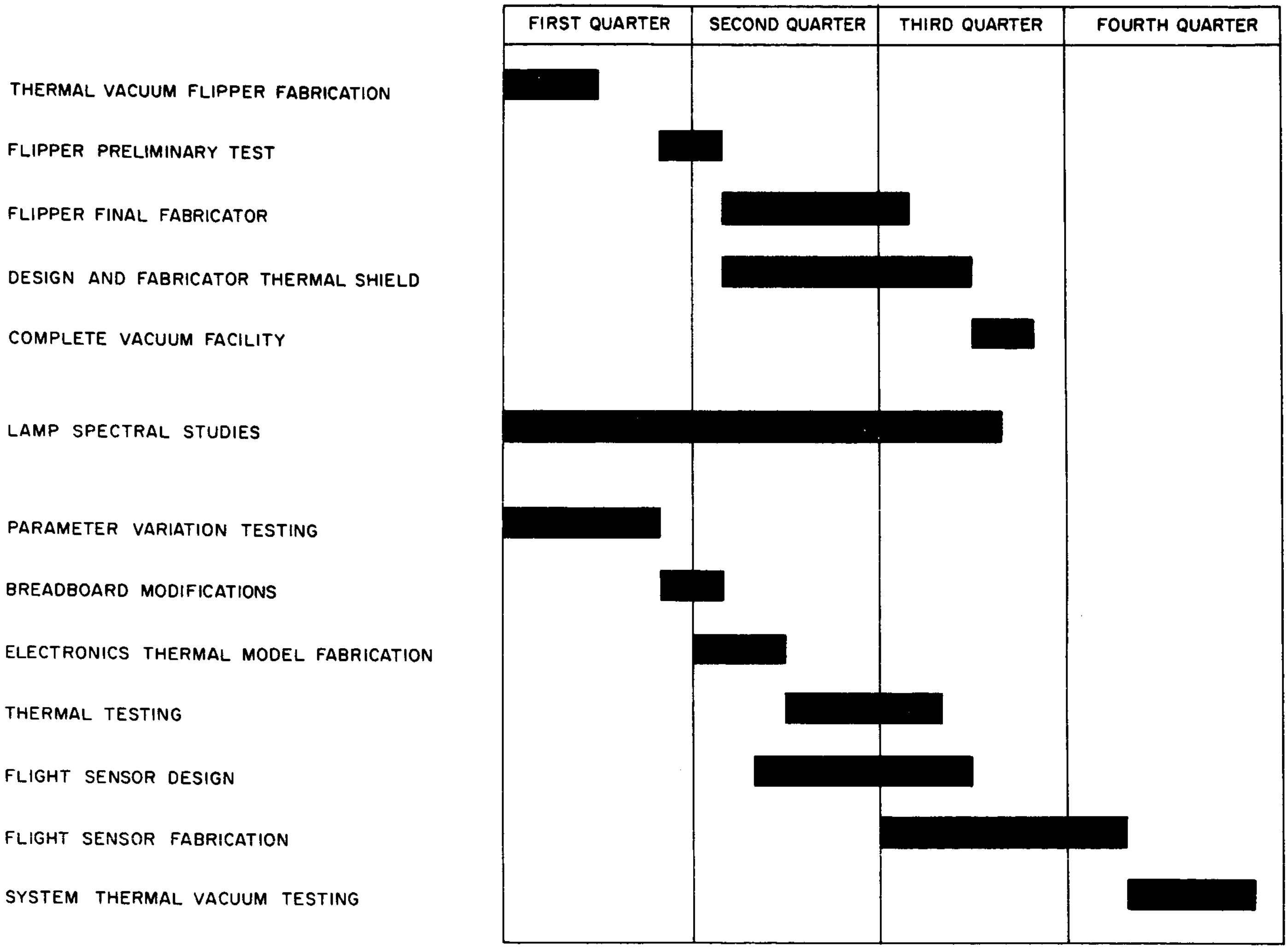

Fig. 1. Advanced magnetometer FY 1966 schedule

ENERGETIC PARTICLES (188-46)

RADIATION EXPERIMENTS
NASA Work Unit 188-46-01-01
JPL 385-60301-2-3280
W. S. McDonald

OBJECTIVE

To develop new experimental concepts and techniques for the study of high-energy radiation, both planetary and interplanetary. Current interest centers around a spherical spark chamber and a low-energy solid-state telescope, both designed primarily for the study of solar-flare radiation phenomena.

SPARK CHAMBER

The primary objective of the spark chamber program for FY 1966 is to conduct two balloon experiments using progressive developmental models of the spark chamber system. The first of these flights (a low magnetic latitude flight) is scheduled to be made from Palestine, Texas, during late March 1966. The second (a high magnetic latitude flight) is to take place from Fort Churchill, Canada, during August 1966.

The Fort Churchill chamber is designed to measure the energy spectrum and angular distribution of protons above 50 Mev and alpha particles above 200 Mev. The chamber will also be adapted for making neutron measurements if preliminary experiments prove this to be feasible. A schematic drawing of this chamber is shown in Fig. 1. The instrument consists of 6 double spark gaps which form the sides of a 6-in. cube. Scintillation counters for triggering the chamber and providing information on the energy of the particles surround the cubical array of spark gaps. Inside this main spark chamber is a smaller 3-in. chamber of similar configuration. The 3-in. chamber provides the neutron detection feature of the instrument (see discussion below).

All of the spark chamber plates consist of fine wires strung 16 to the inch on an insulating frame, so that most of the area of the plate is open. Each wire passes through a magnetic core. When a charged particle passing through the chamber triggers the high voltage and draws a spark, the core associated with the particular wire that carries the spark current is flipped, and that wire can be identified by examining, electronically, the state of the core system associated with a given plate. Adjacent spark gaps have plates with wires strung in mutually orthogonal directions. Therefore, identification of the current-carrying wires in adjacent gaps is equivalent to identification of the position in the chamber at which the spark occurred.

On each outside face of the larger spark chamber are two planar plastic scintillators, optically isolated from each other. A charged particle passing through any two inner scintillators will trigger the spark chamber high voltage. The direction of the particle can be inferred, with an angular accuracy of about 2 deg, from the location of the sparks in the outer spark gaps. Particle energy information is obtained by observing the number of scintillators penetrated and by performing a pulse-height analysis in each scintillator.

The low-latitude-balloon-flight will constitute a flight feasibility study of an elementary spark chamber. The instrument for this flight is a simplified version of the instrument described above. It consists of only two faces of the cubical chamber shown in Fig. 1. A block diagram of this instrumentation system is shown in Fig. 2. The electronics for the low latitude and high latitude chambers are basically the same and are therefore essentially interchangeable.

At the time of this report the design of the low latitude chamber and associated electronic system is complete. Procurements for key components of the chamber, electronics system, and balloon operational support system have been initiated, and fabrication is underway.

Meanwhile, design of the Fort Churchill chamber has been initiated. Tests are being conducted to see if smaller basic components can be used for this chamber than those used in the low latitude chamber. For example, can the 2-in. photomultipliers used in the low latitude chamber be replaced by 3/4- or 1-in. photomultipliers?

On a second priority basis, a test spark chamber is being fabricated in order to check the experimental feasibility of detecting neutrons by filling the chamber with helium-3 and looking for the reaction

$$ {}_{0}n^{1} + {}_{2}He^{3} \rightarrow {}_{1}H^{1} + {}_{1}H^{3} + 0.764 \text{ Mev.} $$

If these tests prove successful, and if the neutron detection feature can be incorporated into the Fort Churchill chamber without introducing excessive complexity, then an experiment for measuring the energy spectrum and angular distribution of neutrons greater than 2 Mev will be performed at Fort Churchill also.

The neutron detection scheme can be understood by referring to Fig. 1. If a sufficiently energetic neutron enters the chamber and reacts with He^3 inside of the smaller 3-in. cubical spark chamber, then the recoil proton and triton will pass through the gaps of both the inside 3-in. chamber and outside 6-in. chamber and be detected by the scintillation counters. The angle between the proton and triton can thus be determined and the energy of the reaction measured. Under the proper conditions the angle-of-arrival and energy of the incident neutron can be determined.

LOW ENERGY PARTICLE TELESCOPE

The charge-sensitive field-effect transistor preamplifier design was completed and tests were performed on the flight-type version of the amplifier. It was determined that the amplifier was capable of a noise resolution of 16 Kev FWHM (full width at half maximum) for a 100-pf detector; except for final packaging the amplifier is complete. It is described in Ref. 3.

The response of selected detectors to light was measured and showed that with no additional light shielding the FWHM noise resolution would be degraded by about a factor of two with an illumination in the range of 0.5 to 1.0 foot candles.

Dead layer measurements were made on two detectors. This line of effort was largely terminated at JPL with the departure of H. R. Anderson for Rice University. However, Dr. Anderson plans to continue work at Rice.

PUBLICATIONS

1. W. S. McDonald, L. L. Lewyn, "The JPL Spark Chamber Program," SPS 37-35, Vol. IV, September, 1965.

2. L. L. Lewyn, "A Nanosecond Rectangular Wave High Voltage Modulator for a Spark Chamber," SPS 37-36, in press.

3. R. F. Lockhart, "Low Noise Amplifier for Solid State Detectors," SPS 37-35, Vol. IV, September, 1965.

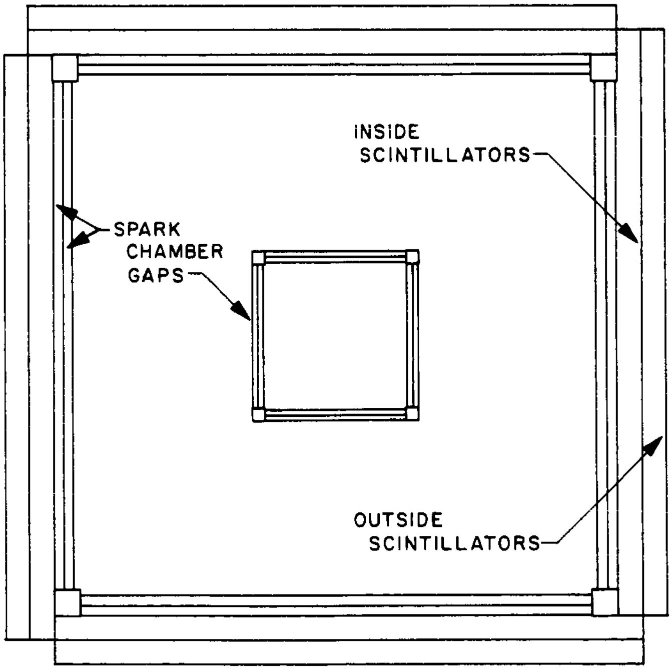

Fig. 1. Omnidirectional spark chamber

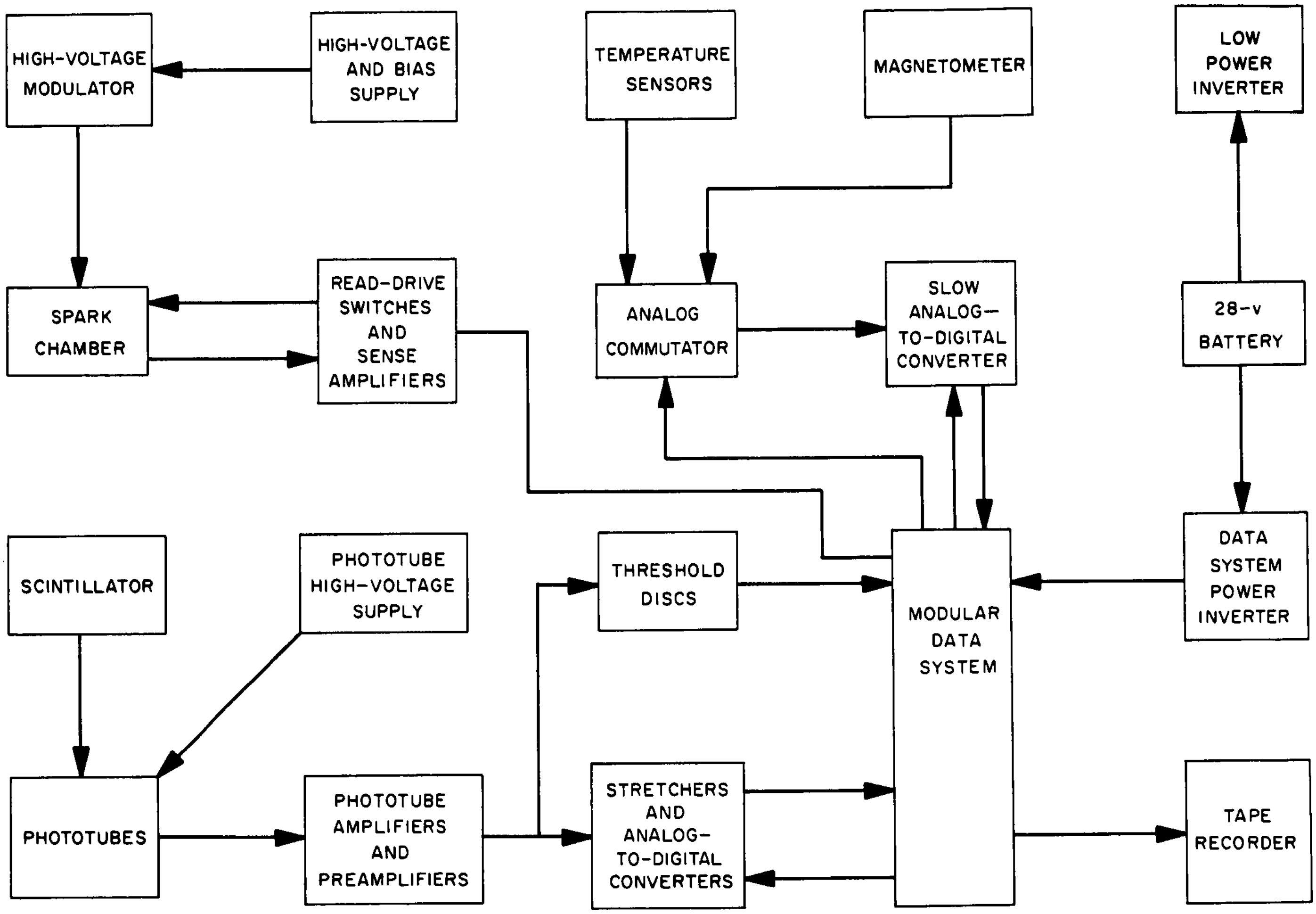

Fig. 2. Block diagram of low altitude balloon experiment

SOUNDING ROCKETS (879)

EXPERIMENTS (879-10)

AEROBEE UV DAYGLOW AND AURORA

NASA Work Unit 879-10-01-55
JPL 745-10101-0-3280
C. A. Barth

OBJECTIVE

To conduct ultraviolet experiments from rockets in the Earth's upper atmosphere on the ultraviolet dayglow and aurora and the ultraviolet albedo of the Earth and Moon.

COMETARY OBSERVATION

Aerobee 4.143 was launched on October 20 for the purpose of observing Comet Ikeya-Seki. The payload consisted of a filter wheel photometer and a 0.25-meter scanning UV spectrometer (scanning from 1100 to 3400 A) with a 0.5-meter telescope.

The rocket and attitude-control system performed satisfactorily and carried out the programmed maneuvers which should have brought the comet into view. The instruments also performed satisfactorily; however, no spectral lines were observed which could be associated unambiguously with the comet. All lines appeared to represent solar contamination — sunlight reflected on the walls of the instrument. This result was later realized to be consistent with the unexpected metallic composition of the comet revealed by ground based observations.

A filter photometer has been prepared for a "piggy-back" flight on W. G. Fastie's rocket scheduled to fly from Ft. Churchill in February. Another payload has been assembled and calibrated prior to shipment to the University of Colorado. It is scheduled for a flight in the spring.

JPL participation in this task effectively terminated on December 31, 1965.

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Part C
Bioscience

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BIOSCIENCE (189)

ENVIRONMENTAL BIOLOGY (189-54)

BIOSATELLITE FLUOROMETRY EXPERIMENT
NASA Work Units 189-54-01-04*
H. O. Kruger

OBJECTIVE

A study of primate metabolic balance during prolonged weightlessness will be made with Biosatellite D. The concentrations of calcium, creatine, creatinine, and urea in the urine will be measured during flight. The work at JPL is divided into developing assay methods, developing the technology for automating these methods, as well as designing and fabricating the flight instrumentation.

GENERAL PROGRAM

The past six months have been spent in subsystem studies as well as reducing the assay methods and experimental techniques to flight-type systems. Early in the next quarter, this operation will be completed. Engineering is started on the mechanical design and is well developed for the electronics. In the following quarter, a type approval system will be completed and tested.

A number of meetings have been held with representatives of the participating organizations. These are Ames Research Center (Project Manager), General Electric Company (Prime Contractor), Manned Spacecraft Center, University of California at Berkeley, University of California at Los Angeles, and University of Southern California. The subjects of the major meetings were:

1. Experiment package configuration.
2. Concentration base lines for analyses.
3. Schedules and interface requirements.
4. Experimenter's review of Launch Operation Plan, Flight Operation Plan, and Recovery Operation Plan.
5. Urine transport system.
6. System test at UCLA.

PRIMATE URINALYSIS (JPL 301-10102-2-3260; JPL 386-40102-2-3260)

The previously described assay methods were modified several times to aid the breadboard development.

A base line study of the four primate urine constituents has been started, using the primate urine sources at Dr. Nello Pace's laboratory and Dr. A. Crockett's

*Jointly funded under NASA Code 981-10-03-02-55

laboratory, by the developed assays. The purpose is to establish the concentration limits required for the flight instruments, as well as obtain background information.

Urine samples were collected and analyzed from one uncatheterized animal for three days and from two catheterized animals for three weeks. The conditions were considerably different from those planned for the flight, consequently the spread in the results was larger than planned. This has provided experience useful in optimizing the assay methods.

Some interface problems such as interference of bacteriacides on assay have been examined, and the results furnished to the prime contractor.

Future work will include additional base line studies with a greater number of catheterized primates kept under conditions closely resembling those planned for flight. Feeding and liquid intake will be controlled as well as temperature. This study will be carried out for at least 30 days.

SCIENTIFIC FEASIBILITY STUDIES (JPL 301-10102-2-3260; JPL 386-40102-2-3260)

Preliminary Breadboard

An automated breadboard using pumps and a flowthrough optical cell was completed for each of the analyses. Calcium and urea were performed fluorometrically. Creatine and creatinine were performed colorimetrically. The following subsystems were developed.

1. Pumps. Peristaltic pumps of various sizes were examined for flow reproducibility and durability. Tubing of several materials was tested, and pumps were designed and fabricated for each of the three systems.

2. Flowthrough Optical Cell. Both glass and platinum were used in conjunction with optical filters to construct various cells of different designs. The final design was a lens system for illuminating and for collecting the light. Colorimeter and fluorometer cells of less than ten microliters internal volume were utilized.

3. Illumination. Miniature tungsten lamps were used for all systems in place of the less intense discharge lamp. A satisfactory light source in the required spectral region was accomplished by high voltage on the lamp and efficient optics. The lamp life is adequate, being over 1000 hrs.

4. Heaters. A more efficient heater was developed, and it consisted of a platinum tube wrapped around a small heated wire coil.

5. Detectors. Cadmium sulfide detectors were used for all units.

6. Control units. Control systems were built for continuous operation of each breadboard and were designed to be easily reprogramed as required by the test work.

7. Calibration and Tests. Calibration fluids were used to test the units for several months of continuous operation. This was followed by a period of primate urine obtained from the experimenter.

Final Breadboard

Due to the weight restrictions, it became necessary to develop a second design of the breadboard, and its fabrication is almost completed. This system is a batch process in which the test is performed in a miniaturized optical cell. The cell is filled and emptied by a motorized piston. The heating and optical measurements are carried out when the test material is in the cell. Valves are used to direct the materials during filling and emptying, and a common peristaltic pump used to fill and clear the lines.

1. Materials. Various materials have been tested for chemical compatibility and physical qualities. Kel-F is used for almost all parts in contact with fluids.

2. Optics. The optics are similar to those used for the other breadboard; however, a double beam system is used as will be done in the flight instruments.

3. Control Units. Control units have been designed and are being fabricated for fully automating the three systems.

4. Testing. The first unit has been manually tested to ascertain problem areas. The major problems involved leaking of valves, heating, mixing of materials, last-minute flexibility of the method. Development and test programs were satisfactorily completed for each of these areas. The interaction of the subsystems is yet to be studied.

Sample Handling System

A sampling system to handle the urine on board the spacecraft has been designed and tested on a laboratory scale. The unit consists of two passive filling containers, a check valve, solenoid valves, and a miniaturized back pressure regulator. A breadboard is being constructed to test its compatibility with interface specifications.

Future Activities

The piston displacement breadboards will be completed and evaluated. Life and the ability to pass certain qualification tests will be determined. These breadboards will be used in a systems test at UCLA next quarter.

FLIGHT INSTRUMENTATION (JPL 386-40101-2-3220; JPL 301-10101-2-3220)

During the first quarter of FY 1966, design and development of the electronics for the flight prototype has been completed for the following items:

1. A stabilized light source for use in both the colorimetric and fluorometric analyses.

2. The signal detection amplifiers that will be used with both types of experiments.

3. Preliminary development of the data sampling and processing equipment, including the read in and out scanners, storage units, and the necessary clocks has been completed.

Procurements have been initiated for those components to be used in the flight and qualification hardware. These components, once received, will be processed through the quality control group in order that they may evaluate the quality of the components and make preliminary measurements. After this, these components will be put into bonded stores until such time as needed for incorporation into flight hardware.

During the second quarter, some of the interface information was formally released. This included the electrical interface specifications and a portion of the urine collection and proportioning system as well as instrument packaging. Power/thermal profiles have been tentatively released, but final release will not occur until an actual unit has been fabricated and is in operation. Thermal stabilization has been completed on the regulated power supply electronics and the signal detection amplifier electronics. These units will operate over the range of 0 to 50°C without any degradation in performance. The thermal control circuitry used in actively controlling the temperature of the test cells has been completed, and is operational over the temperature range indicated above. The actual controlling temperatures are set up at slightly above 100°C for the urea and creatine-creatinine experiments, and at a level of approximately 37°C for the calcium experiment. In addition, during this second quarter, bids were released to vendors for fabrication of the data and logic sequencing system electronics. Bids were received back and evaluated, and the vendor has been selected. The breadboard prototype for the sequencing of the calcium experiment has been completed. Performance is satisfactory. Work is under way in the assembling of the equipment to be used in the associated ground equipment, consoles, and in the sequencing systems for urea and the creatine-creatinine experiments. It is anticipated that these sequencing units will be completed the early part of next quarter.

Component testing on motors and lamps has been carried out in order to verify that these components will pass the necessary qualification levels required for flight hardware. Other components and subsystems will be evaluated during the first few weeks of the third quarter. Almost all of the mechanical components will be developed with completion of the breadboards. The final engineering drawings are being prepared from this work.

EXOBIOLOGY (189-55)

GROWTH AND PHOTOSYNTHESIS STUDIES

NASA Work Unit 189-55-02-01-55
JPL 386-51101-2-3260
G. L. Hobby

OBJECTIVE

To develop a life-detection experiment which will test for light dependent fixation of carbon dioxide. The objectives for the remainder of the year are to determine the possible artifacts in the experiment due to nonbiological uptake of carbon dioxide by soil samples, and the most favorable conditions for carrying out this experiment.

During the past two quarters most of the work in this program involved the design and construction of new experimental apparatus. Seven incubation chambers were fabricated for exposing soil samples to light in an atmosphere of radioactive carbon dioxide. Each chamber holds six samples and thirty-six can be run simultaneously in a single experiment. The chambers can be filled with gas and purged either together or individually and the apparatus is readily adapted to incubating samples under anaerobic conditions.

Two anaerobic, photosynthetic species of bacteria have been successfully cultured. One is chlorobium obtained from Dr. Stanier at the University of California, Berkeley and the other, chromatium. The chromatium is not only a photosynthetic anaerobe but it is also halophilic. These organisms will be used in pure cultures and mixed with soils to study optimal conditions for the experiment.

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FLUOROMETRY

NASA Work Unit 189-55-02-02-55
JPL 386-50201-2-3260

J. H. Rho

OBJECTIVE

To develop fluorometric procedures for detecting the presence of general organic compounds, essential biochemicals, and metabolic functions, such as photosynthesis, respiration, and growth of microorganisms.

DETERMINATION OF BIOLOGICAL MOLECULES

Some data have been obtained on the maximum sensitivity of the method for detecting nucleic acid bases and for measuring the chlorophyll content of both photosynthetic microorganisms and of soils. The method shows sensitivity to the nanogram level for purine bases. RNA and DNA can be detected at the ten- to twenty-nanogram level which is equivalent to about ten thousand microorganisms. The high chlorophyll fluorescene makes detection of a few hundred chlorella cells possible.

DETECTION OF ORGANICS

A prime effort was made to find pyrolysis conditions which yield the simplest mixture of fluorescent compounds. Organic compounds of any class yield quite similar complex mixtures of fluorescent polycyclic aromatic products when they are heated strongly. At lower pyrolysis temperatures one obtains fluorescent mixtures which may be simple and also somewhat characteristic of the parent source. It may then be possible by selection of pyrolysis temperature and fluorometry techniques to arrive at information on the chemical nature of organic matter in pyrolyzed soils.

We have pyrolyzed representative sugars, amino acids, hydrocarbons, and bacterial cells at several temperatures and examined the products by means of TLC and gas chromatography. The amino acid L-lencine when heated for 30 min at 300° C in quartz yields a mixture of about six compounds of which only two are fluorescent. A main product, the dipetopiperazine, also yields the same fluorescent product when it is pyrolyzed. Glycine and α-amino-butyric acid pyrolysates gave similar TLC fluorescent patterns. The fluorescent compounds are as yet unidentified though they appear to be similar to pyrazines according to preliminary IR and MS data.

FUTURE WORK

We plan to characterize the chemical nature of the pyrolysis mixtures obtained by pyrolyzing organic compounds at several temperatures. We want to relate starting material composition to fluorescence yield and to simplicity of mixture in order to interpret the data most simply.

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BIOSCIENCE EXPERIMENT DEVELOPMENT
NASA Work Unit 189-55-02-03-55
JPL 386-51301-02-3260

Due to the intensive efforts required for the Biosatellite Program all manpower assigned to this program have been used for the Biosatellite. Little progress has been made during this period of FY 1966. A small effort was initiated to determine the feasibility of an infrared technique for biological identification using a microspectrophotometer. The first results were encouraging but not conclusive.

JPL Technical Memorandum No. 33-272, Vol. I

EXOBIOLOGICAL INSTRUMENTATION
NASA Work Unit 189-55-02-04-55
JPL 386-51401-2-3220

J. R. Clark

OBJECTIVE

Work charged to this unit consisted primarily in the development of the data handling and sequencing systems for the Biosatellite Project (NASA Work Unit 189-54-01-04-55). Development work for this project is directly applicable to Exobiological Instrumentation in that the functions to be implemented are similar.

DATA HANDLING SYSTEM (See Fig. 1 and 2)

The data handling system (DHS) for the Biosatellite Project performs the following functions:

1. Samples the outputs of the data amplifiers.
2. Codes the sampled output into a binary number.
3. Stores seven such binary numbers.
4. Performs parallel to serial conversion.
5. Multiplexes (samples) the seven digital words with nine analog voltages and presents the combination to the spacecraft telemetry commutator for further encoding and transmission to the ground station at selected times.

The entire system, with the exception of the input and output samples (multiplexers), is comprised of the Texas Instrument Series 51 Integrated Circuits (RCTL logic). This series was chosen because of its low power consumption. All gates and binaries have a 5.1K collector resistor so that with a supply voltage of 6 v, the device dissipation is about 7 mw. The input and output samplers utilize field effect transistors (2N 3382 Siliconix) operating sequentially as switches.

The complete data handling system has been breadboarded and operated over the past three months. The DHS system is now undergoing modifications to integrate it with the experiment sequencers.

SEQUENCE SYSTEM

The sequencer performs the following functions:

1. Receives timing pulses from the spacecraft and generates experiment initiate commands at 0, 3, 9, 15, and 21 hr for the calcium, urea, creatine-creatinine experiments.

2. Insures ample urine is available at the beginning of each sequence.

3. Positions the two valves associated with each experiment.

4. Performs control of the micro-syringes which are used to fill and empty the test chambers.

5. Performs control of the waste pumps which discharge the stored urine after the experiments have received their sample.

6. Controls the data handling system in supplying storage clear pulses encoding triggers, and updated experiment results.

The simplified control logic of an experiment is shown in Fig. 3. This figure shows a closed loop system which is initiated by the experiment initiate command from the experiment timer shown in Fig. 1. This allows the decoder shown in Fig. 3 to set valves V_1 and V_2 to the correct position. When the valves arrive at the correct positions, a command is sent to either the micro-syringe or the waste pump (depending on the sequence). When the micro-syringe or waste pump cycle is complete, a command is then sent via the feedback loop to advance the counter one count. This drives the valves to a new set of positions. This ring-around operation continues until the feedback count pulse causes no change in the valve positions. This puts the experiment sequencer in a standby mode awaiting the next experiment initiate command at the beginning of the next six-hour period.

The complete sequencing system is designed using the same Texas Instruments Integrated Circuits as the DHS system. The DHS and sequencing systems will use about 315 integrated circuits or chips.

The experiment timer, shown in Fig. 1, and calcium sequencer, shown in Fig. 3, are breadboarded and perform logically as designed. Simulation of limit, cycle, and valve position switches is not good. Parts should arrive shortly to allow ideal simulation of all experiment electrical outputs; thus we will be able to give the sequencer a good evaluation.

A modular packaging design is being utilized for the flight hardware. Fifteen integrated circuits are allocated to a module with 100% replaceability. The modules will be stacked end to end to form a volume 5 x 6 x 1-1/2 in. for the total 315 chips. A contract has been let for fabrication of 110 modules.

AUXILIARY EQUIPMENT

Also charged to this work unit is the design of the bench checkout rack for systems test of the flight electronics and the Auxiliary Ground Equipment (AGE) racks and consoles for operation and test of the flight package at JPL, Goddard Space Flight Center, and Cape Kennedy. The bench checkout equipment has five monitoring and mounting panels designed, and is about 70% complete on fabrication. Three AGE racks have been obtained, and the required three consoles are on order. Requirements for the AGE system have been established, and long lead items have been ordered.

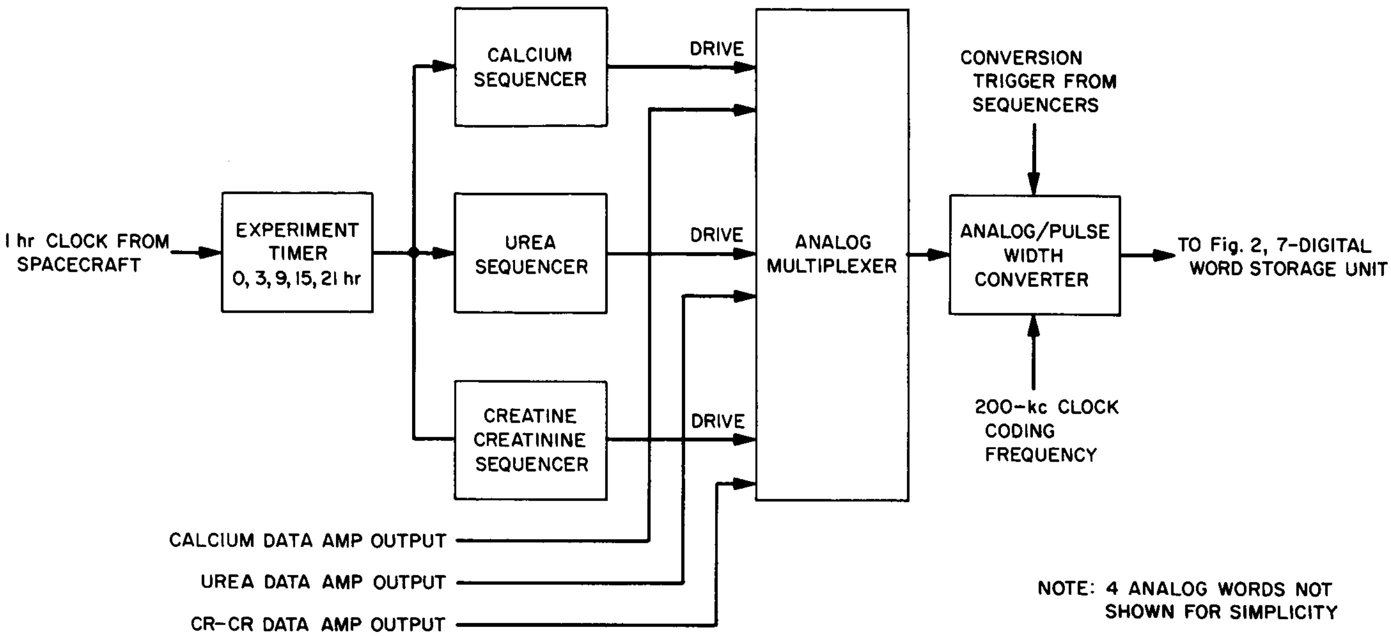

Fig. 1. Biosatellite system signal flow diagram, analog

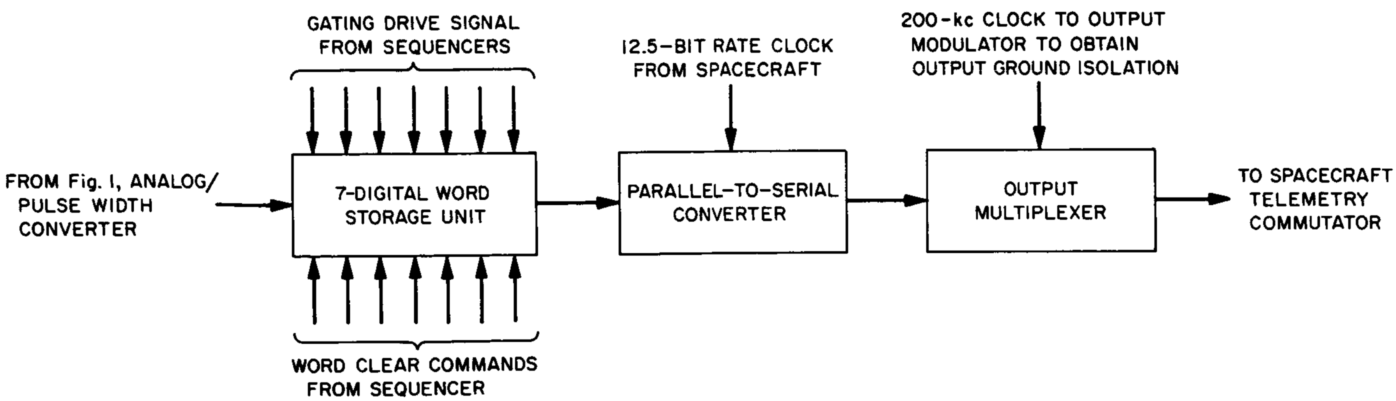

Fig. 2. Biosatellite system signal flow diagram, digital

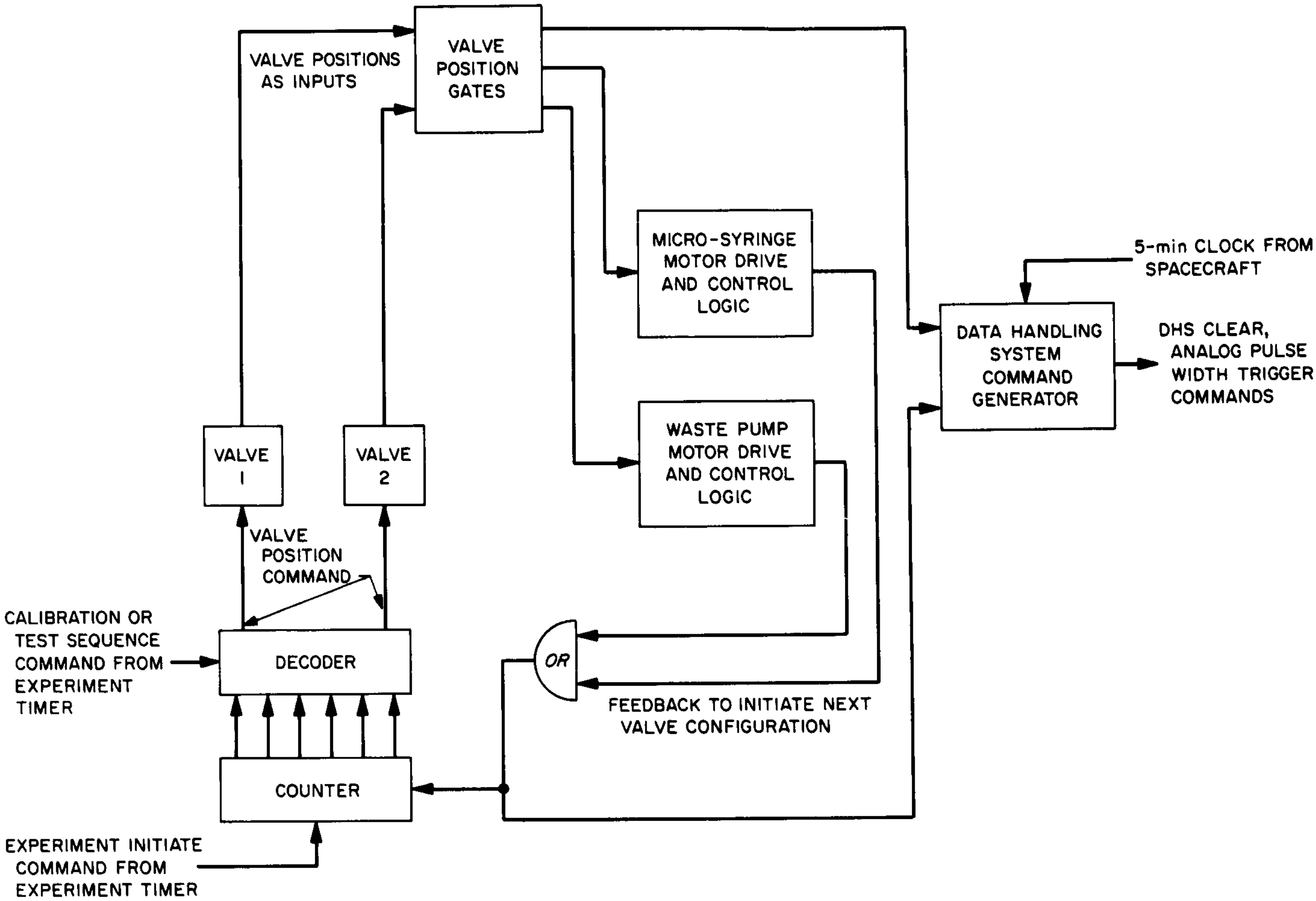

Fig. 3. Basic experiment sequencer logic

DETECTION OF LIFE-RELATED COMPOUNDS
NASA Work Unit 189-55-02-08-55*
JPL 386-51201-213260
C. H. Stembridge

OBJECTIVE

The objective of this work unit is to provide information of use in defining a technique for detecting the presence of and for analyzing organic compounds in a planetary surface. The analytical procedure being developed is based on the combined techniques of gas chromatography and mass spectrometry. The procedure being followed is: (1) thermal treatment of the sample to yield volatile fragments, (2) separation of these volatiles by gas chromatography, and (3) mass spectrometic determination of the components present in each gas chromatograph peak. In addition, differential thermal analysis of a surface sample will be performed in both oxidizing and reducing atmospheres to detect a disequilibrium between the surface and the atmosphere.

PYROLYSIS STUDIES

The activities under this study are concerned with methods of sample preparation and treatment for use in the detection of organic compounds present in soils. Thermal treatment procedures were used to convert the nonvolatile material to substances of sufficient volatility to be separated by gas chromatography. "Pyrograms" of six different soils have been obtained, showing the presence of many different peaks in the chromatogram. Much trouble has been encountered in identifying these compounds represented by these peaks. The technique used has been to trap the compound in a collection tube, transfer the tube to another location, introduce the sample to the inlet system of a mass spectrometer, and obtain a mass spectrum. Due to the small amount of compound in each peak, and a low sensitivity in the mass spectrometer, few useful analyses have been obtained. This problem will be solved when the high resolution mass spectrometer is placed into operation.

HIGH RESOLUTION MASS SPECTROMETER

The high-resolution mas spectrometer offers the opportunity to greatly accelerate the progress being made in the Detection of Life-Related Compounds program. A laboratory system will be constructed consisting of an experimental pyrolysis furnace, gas chromatograph, carrier gas separators and sample enrichment devices, and the high-resolution mass spectrometer. With this system, the mass spectrometric data will be recorded on magnetic tape. Using suitable programs, a computer analysis will yield an "element map" allowing structure identification. This system will be placed into operation in the third quarter of FY 1966.

*Jointly funded under NASA Code 185-37-26-09-55

DTA STUDIES

A miniature differential thermal analysis assembly has been constructed utilizing a hydrogen flame for effluent gas detection. Preliminary DTA studies have been carried out on various organic materials such as coal, latterite soils, and peat. In addition, a furnace of special design to minimize sample residence time has been constructed for the organic pyrolysis study. This furnance will allow for a shorter time between samples, and will avoid flow stoppage since no small orifices are involved.

Future work includes a study of DTA under oxidizing and reducing conditions to aid in detecting disequilibrium between a soil and the atmosphere. It is also planned to study the DTA curves of inorganic constituents under these differing environments to aid in identifying the inorganics.

DESERT MICROFLORA
NASA Work Unit 189-55-04-01-55
JPL 386-50301-1-3260
R. E. Cameron

OBJECTIVE

The primary objectives of this program are fourfold: (1) to determine the evolution of biologically significant gases in relation to activity and abundance of physiological groups of microflora in desert soils, (2) to study the influence of various environmental factors on soil microflora, (3) to study and identify microbial isolants from desert soils, and (4) to provide desert soils, microbial isolants from these soils, and background information on these soils for JPL and other NASA-supported life-detection and related programs.

SOIL GAS EXCHANGE

At the present time a two-column system has been completed for resolution of CO_2, O_2, and N_2 with silica gel and molecular sieve columns. Technical difficulties have been encountered in choice of mesh size for the molecular sieve column and because the temperature sensitivity of the system is too great. Lack of technical support has delayed this phase of the program.

INFLUENCE OF PROTECTIVE ENVIRONMENTAL CHAMBER ON MICROFLORA ABUNDANCE

Soil samples have been preserved under various environmental conditions so as to determine their influence on soil properties. Eighteen samples of high altitude soils protected by environmental chambers were investigated after a time period of one year and a comparison made of the original abundance of aerobic, anaerobic, and microaerophilic bacteria, algae, and molds. Significant differences were obtained for microflora in some of the chambers. For example, molds were more abundant in white chambers. High counts were obtained for the microaerophils, but the lowest abundance for nearly all microflora was obtained in black chambers. Chamber temperatures > of 135 to 150°F had no surviving algae.

DESERT SOILS

Soil samples have been obtained from the Atacama Desert northeast of Antofagasta, Chile and near the Aswan Dam, Egypt. These deserts are two of the driest regions on this planet. A low abundance of common groups of microflora was found in these soils, except for the microaerophils, which were cultured in fluid thioglycollate medium. With this medium, all dilution cultures were positive for growth at 10^3 to 10^7/gm of soil. Specialized groups of microflora are evidently present in these soils. Algae (only *Nostoc muscorum*) was found in only one of the 10 soils examined. In all soils, a greater abundance of aerobic bacteria were found below the soil surface than in the surface 2 cm of soil.

CONTRACT WITH OREGON STATE UNIVERSITY

Under the supervision of Prof. Walter Bollen, bacterial and actinomycete isolants from our desert soils are being identified and characterized. At the present time, over 200 isolants have been sent for study. A detailed progress report has been received for soil diptheroids. These bacteria resemble the described genus of Corynebacterium in some ways, but on the basis of specific differences in biochemical properties, they warrant being placed in one or more new genera.

SOILS AND/OR CULTURES

Soils and/or cultures have been distributed to JPL and various NASA-supported and related programs. Those supplied outside of JPL include the following:

Dr. Seymour West, Melpar

Dr. Richard Walwick, Aeronutronic

Dr. Richard Weston, University of Rochester

Dr. Richard Toolee, Northrop

Dr. Emanuel Rudolph, Polar Research Institute, Ohio State

Dr. John Skujins, University of California, Berkeley

Mr. George Clark, California Institute of Technology

Dr. Klaus Biemann, Massachusetts Institute of Technology

Dr. S. R. Lipsky, Yale University

Dr. R. H. Kellogg, University of California, Berkeley

Dr. E. H. Wood, Mayo Foundation

CONTRACT TO BE AWARDED

A contract for identification of molds and fungi isolated from desert soils is under discussion with Dr. A. Boyle, Department of Plant Pathology, University of Arizona, Tucson, Arizona.

ATTENDANCE AT MEETINGS AND SIGNIFICANT DISCUSSIONS

1. Soil Science Society of America, Columbus, Ohio, October 30 to November 3, 1965.

2. Drs. F. Ugolini, E. Rudolph, and C. Bull, Polar Research Institute, Ohio State University, November 4, 1965.

3. Dr. George Llano, Antarctic Programs Director (at JPL), December 3, 1965.

4. Dr. John J. Skujins, University of California, Berkeley (at JPL), November 8, 1965.

5. Mr. Pete Chapman, University of Nevada (NASA Remote-sensing project at JPL), October 11, 1965.

6. Dr. Francis Drouet, Academy of Natural Science, October 29-31, 1965.

7. Dr. Ed Sie, North American Aviation, October 8, 1965.

8. Mr. C. Hagen, IITRI (at JPL), November 17, 1965.

9. Dr. Richard Weston, University of Rochester (at JPL), October 8 and December 10, 1965.

10. Drs. Lew Stolzy, John Letey, and Clayton Jensen, University of California, Riverside, July 19, 1965.

11. Dr. John Opfell, Aeronutronics (at JPL), July 16, September 30, and December 1, 1965.

REPORTS AND PUBLICATIONS

1. "Soil Chemistry and Sampling," In Press: "Biology and the Exploration of Mars."

2. "Soil Studies - Microflora of Desert Regions. VIII. Distribution and Abundance of Desert Microflora," JPL SPS 37-34, Vol. IV, August 31, 1965.

3. "Soil Studies - Desert Microflora. IX. Measurement of Soil Moisture Suction by Thermal Conductivity Probes," JPL SPS 37-35, Vol. IV, September 30, 1965.

4. "Soil Studies - Desert Microflora. X. Soil Properties of Samples from the Chile Atcama Desert," JPL SPS 37-35, Vol. IV, September 30, 1965.

5. "Sampling and Handling of Desert Soils," JPL Technical Report, in final preparation.

6. "Observations on Translucent Substrata as Desert Algal Habitats," JPL SPS, in preparation.

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BIOSAMPLING

NASA Work Unit 189-55-04-02-55
JPL 386-50402-2-3220

S. B. Tuttle

OBJECTIVE

The objective of this effort is to evaluate and optimize a sample collection system suitable for life detection experiments. An aerosol system will work at ambient pressures of 5 millibars, and a cartridge of carbon monoxide provides sufficient primary jet gas for a sampling period of 2 min.

The biosampling tests at JPL using the aerosol method with a jet pump located just prior to the cyclone separator produced acceptable results. The performance of this system can be optimized, and technical details are presented in a report now being edited.

Litton Industries have completed their contractual activities for JPL except for writing the final report. This will be delivered early in January 1966, and it will include a working prototype model. Included in this effort is ejection equipment using high-pressure gas to unfurl and throw out the suction lines. The approach used by Litton is similar to that of JPL except that the jet pump is located at the exhaust of the cyclone separator. This places the cyclone separator and the biological sample under reduced pressure during the sample acquisition process.

The optimum design parameters of an aerosol collection system involve the size of various components. The physical size of a jet pump having a primary orifice of 0.010-in.-diameter and working at 5-millibars suction pressure is hardly conventional. If the performance is optimized for a suction pressure, say 25 millibars, the performance degrades slowly as the suction pressure varies either up or down. Incidentally, a jet pump which is optimum for 25 millibars of suction will have practically zero efficiency at 1000 millibars, i.e., Earth ambient.

Continuing effort will involve evaluation of the Litton Industry effort. Further testing on Litton's prototype apparatus may be desirable to optimize design parameters for low suction pressures.

A contract has been initiated with the University of Rochester to determine the appropriateness of various soil fractions, locations, and particle size for biological content. The only results obtained during this period are the development of optical techniques for evaluation of the methods to be employed.

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PLANETARY QUARANTINE STERILIZATION (189-58)

MICROBIOLOGICAL FILTERS - LIQUID AND GAS

NASA Work Unit 189-58-00-03-55 (FY 1964)
JPL 386-55803-2-3156

A. S. Irons

OBJECTIVE

Preliminary studies conducted by independent laboratories have indicated that the claims made for the efficiency of some liquid and gas filters may be highly exaggerated. This has been a source of concern because of the critical requirements previously mentioned and the sterilization constraints which have been imposed on all systems of the spacecraft. The present study is designed to evaluate the efficiency and reliability of currently available filters to sterilize liquids and gases. The results of this study will provide the basis for selection of filters acceptable for use in the assembly of space hardware required to be clean and/or sterile. (See JPL SPS 37-29, Vol. IV, "Evaluation of Microbiological Filters for Liquids and Gases.")

INTRODUCTION

Production of certain space hardware, portions of the dry heat sterilization cycle, biological experiments, and maintenance of a sterile spacecraft after terminal sterilization will require sterile filtration. For example, some of the liquids required for extraterrestrial microbiological experiments and certain liquid propellants, as well as battery electrolyte, represent a few of the substances that may be degraded by dry heat and/or chemical sterilization and may therefore require sterilization by filtration. Also, certain critical areas, such as spacecraft assembly areas, glove box systems, and environmentally controlled areas housing spacecraft immediately prior to launch have requirements for sterile gases. Control and conditioning equipment used to deliver sterile gas to these areas will have to have incorporated in their systems, one or more filters capable of removing all of the microorganisms that may be entrained in the gases. Gases carried aboard spacecraft, such as the nitrogen used in some altitude control devices, may also have filtration requirements. Thus, the sterility testing of filtered liquids or gases is important in the monitoring of sterilization procedures. Any monitoring techniques must be capable of detecting small numbers of microorganisms in large volumes of liquids and gases.

ACCOMPLISHMENTS TO DATE

Seventy HEPA (high efficiency particulate air) filters were tested by challenging them with an aerosol of viable particles of Bacillus subtilis var. niger spores (Fig. 1). Efficiency was determined by counting the number of organisms collected by air samplers located in the test duct on the downstream side of the filter (Fig. 2, 3, and 4). Calculations indicated a viable particle challenge of 250,000/min. The sampler orifices were designed to be isokinetic for 112.5 linear ft/min (equivalent to 50 ft^3/min in the 8-x-8 in. duct used). Linear velocity profiles across the face of the various filters ranged from zero to over 900 ft/min due to variations in filter media and lack of homogeneity. All equipment including ducts, filters, samplers, isolators,

and related material was decontaminated with ethylene oxide daily. Filter efficiencies based on the number of challenge organisms upstream of the filter versus the number downstream of the filter ranged from 99.9736 to 99.9999%. The size range of the viable particles used made it necessary for the filters to be at least 99.99+% efficient, using this system, before they could be considered acceptable as HEPA filters. Only two (2) groups of filters had zero rejections. Within the other groups rejections on the basis of failure to meet the efficiency requirements ranged from 0 - 75%.

MEMBRANE FILTERS

This phase has been approximately 40% completed. Although membrane filters are generally more reliable than depth filters, there seems to be little correlation between designated pore size and filter efficiency or reliability. One would expect that the smaller pore sizes would be more efficient and that pore sizes of 0.25 microns or less would effectively remove organisms of the size of Serratia marcescens (the challenge organism) but this was not found to be the case. It was concluded that membrane depth filters are unreliable as are membrane filters of small pore size, but some of these results should be held suspect pending further testing. From the tests so far there seems to be little correlation between designated pore size and filter efficiency or reliability. Of the filters tested, ranging in pore size from 0.45 to 0.20 microns, 20% failed to remove 100% of the organisms contained in the media being filtered and were rated unsatisfactory.

The data generated during the period of performance cover two major filter types: the high-efficiency, low-pressure air filters and the liquid filters of membrane construction. Two categories of the four originally proposed remain to be initially investigated; they are evaluation of filters in a pressure gas-flow system and evaluation of filters in a pressurized liquid-flow system. Some work remains to be done in the other two categories mentioned.

CURRENT STATUS

During the report period work was discontinued on this study because of lack of funds to complete the original contract. Although a technical evaluation of the interim final report issued under this contract indicated satisfactory performance of the work accomplished, much of the effort required for satisfactory completion of the study remained to be expended. Work was terminated before completion of the study when the funds allocated under the contract were exhausted.

Further evaluation by the cognizant engineer and procurement negotiator indicated that the contractor could not have possibly completed this contract with the funds allocated because of the techniques which had to be developed and the testing equipment which had to be designed and fabricated.

These evaluations led to the decision to issue a new contract to Wilmot Castle for completion of the study using the techniques and equipment developed. Additional funds were approved and allocated and a work statement was prepared spelling out the additions and modifications which were considered necessary because of the findings under the original contract. It is expected that the contract extension will be negotiated shortly after the first of the year.

FUTURE ACTIVITIES PLANNED

Further work will include:

1. Determination of the comparative efficiencies of the air samplers used to evaluate the HEPA filters in a duct.

2. Determination of whether or not the air velocity profile across the face of HEPA filters is a true indicator of filter efficiency; i.e., the areas of high velocity (above average) equal areas of low bacterial retentive efficiency.

3. Evaluation of the existing HEPA filter data to determine the areas of most frequently occurring penetration, the effect of frame and sealing compounds on penetration and the most efficient HEPA filter material tested.

4. Investigation of the cause of liquid filter failure. This will include examination of filter holders as well as filter media and will involve the use of more than the one organism originally proposed.

5. Evaluation of additional liquid or high pressure gas filters which have been developed since the initiation of this study. This includes filters which may have a bacteriostatic effect and which will require special culturing techniques.

6. Determination of the efficiency of liquid filters placed in tandem and the efficiency of the just-developed presterilized disposable, completely assembled filter units.

Completion of the study will take 58 weeks after initiation of work under the contract extention.

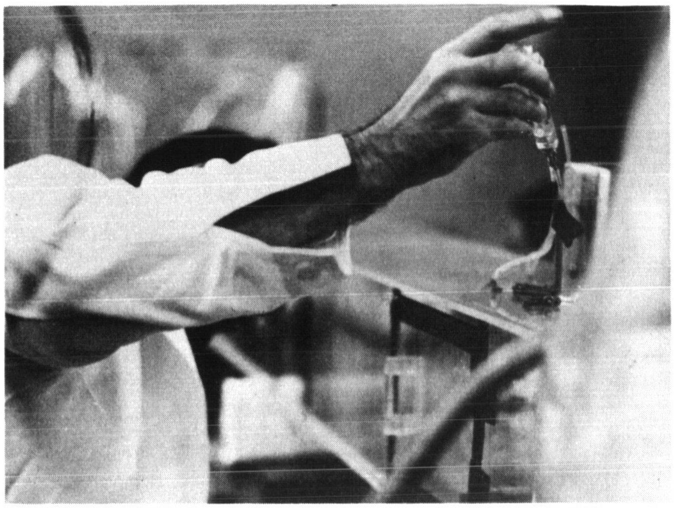

Fig. 1. Introduction of spores suspension into nebulizer

Fig. 2. Inlet for prefilter sampler

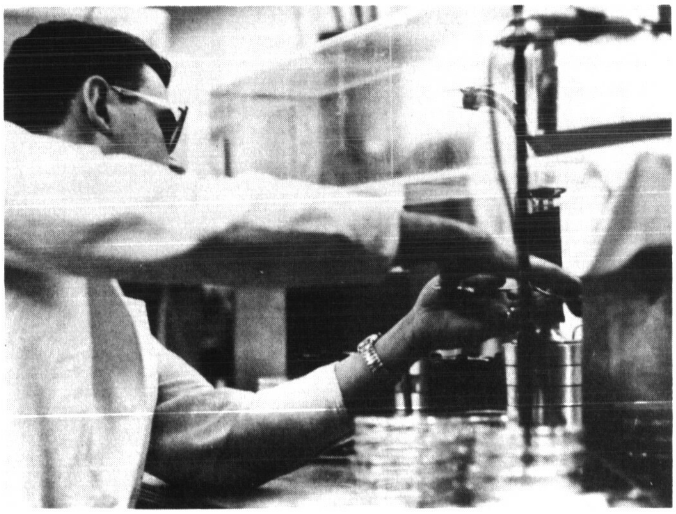

Fig. 3. Postfilter sampler

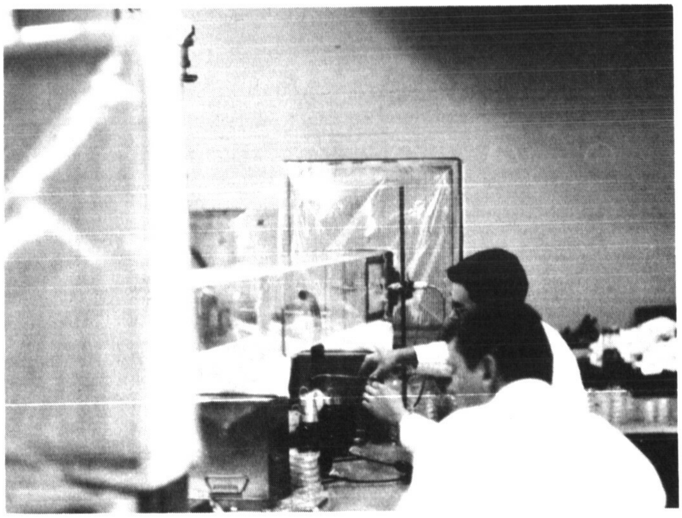

Fig. 4. Overall view of sampling duct and samplers

DEVELOPMENT OF A BIOLOGICAL INDICATOR FOR DRY HEAT STERILIZATION

NASA Work Unit 189-58-00-06-55 (FY 1964)
JPL 386-55806-2-3156

A. S. Irons

OBJECTIVE

The purpose of this study is to develop a reliable biological test system to be used to indicate whether or not sterility is achieved as the result of specified dry heat sterilization procedures. For the purpose of this study the following conditions are considered as the dry heat sterilization cycle: 135° C for 24 hr in an atmosphere of dry nitrogen. (See JPL SPS 37-29, Volume IV, "Development of a Biological Sterility Indicator for Dry Heat Sterilization", by A. S. Irons.)

INTRODUCTION

Biological sterilization regimens require the use of some test procedure which will indicate that a particular sterilization process has or has not attained a high probability of producing sterility. Since the objective of any sterilization process is the death of all biological life associated with the materials being processed, it is logical that the ultimate sterility test should be a test for survival of organisms, i.e., a biological test.

It is well known that the spores of certain bacteria are more highly resistant to adverse conditions than other types of microorganisms. For many years bacterial spores have been incorporated into standardized sterility tests for use with sterilization procedures. These sterility tests, when properly used, have been found to be highly satisfactory. Up to the present time there has been no standardized sterility test organism, or a test system - utilizing organisms - which could be used reliably with the proposed dry heat sterilization procedure. (Reference: "Development of a Biological Indicator for Dry Heat Sterilization", A. S. Irons, Presented at NASA National Conference on Spacecraft Sterilization Technology, November 16 - 18, 1965, Pasadena, California.)

ACCOMPLISHMENTS TO DATE

A survey of plastics, insulating materials, silicones, and ceramics to be used as the carrier for the test organism was completed, resulting in the selection, procurement, and laboratory evaluation of types having properties necessary for the proper fabrication, handling, and stability of the indicator at 135°C. It has been demonstrated that a biological indicator made up of a spore powder tablet (Fig. 1) and a Teflon carrier (Fig. 2) can be produced which will remain viable after exposure, to a temperature of 135°C for a period of up to 20 hr, but the majority of the indicators are rendered sterile in much less time than this (i.e., 61% of the indicators subjected to 135°C were sterilized at times ranging from 4 to 18 hr; 33% survived for 18 hr, and 6% showed organism survival for 20 hr).

In an attempt to obtain reproducible results and to overcome the erractic survival pattern observed, the production of clean, freeze-dried Bacillus subtilis WC 18 spores had been standardized and controlled to prevent incipient germination. Part of the control process required the use of a continuous flow centrifuge, to be

cooled with dry ice to maintain the low temperature required to prevent germination of the spores.

A Bacillus subtilis var. niger strain was found which had greater heat resistance than strains used in many laboratories for thermal resistance studies, and it has been proposed that this organism be used instead of WC 18 in the planned continuation of this study.

Recovery and germination of heat damaged spores, which appeared killed after exposure to a portion of the sterilization cycle, was made possible by agitation of the culture media which provided aeration. In addition to agitation, diphasic cultures, a spore dispersing agent, a cellulose sponge culture technique, and hyperbaric oxygen tension were among the recovery techniques explored.

Even though the Aclar film used to encase the indicator (Fig. 3), as added insurance against nitrogen loss, is permeable to ethylene oxide, this agent can be used to decontaminate the indicator because ethylene oxide will not penetrate the Teflon carrier which contains the indicator organisms. The process of external sterilization of the indicator carrier will be required before it can be introduced into the sterile atmosphere of the hood where it will be opened and the spore tablet transferred to a culture medium.

CURRENT STATUS

During the report period, work was discontinued on this study because of lack of funds to complete the original contract. An interim final report was issued by Wilmot Castle 9/9/65. After a thorough study of this report, an investigation by Procurement and the cognizant scientist of the work accomplished and effort expended, it was decided to fund an extension of the original contract and to increase the scope to include other possible sterilization temperatures. Additional funds were approved and allocated and a work statement was prepared. Recently some questions arose as to the exact use and applicability of the indicator. This, plus the question of whether or not the presently stipulated cycle is too stringent, have caused a delay in this study until the problems are more clearly defined.

FUTURE ACTIVITIES PLANNED

A sterility indicator is to be developed which will produce biological evidence of the proficiency of the proposed sterilization process. The indicator will be used as part of a "system" which will be developed to prove that the proposed sterilization process will consistently sterilize space hardware exposed to it. The "system" will be composed of handling methods, sterilizable hoods sterile transfer and insertion techniques and their use in a sterile atmosphere, culture techniques, and a complete protocol for fabrication and use of the indicator "system". Procedures will be developed to promote the outgrowth of viable but thermally injured spores. This will increase the confidence level that sterility has in fact been achieved. Indicators developed for the NASA stipulated time-temperature will be exposed to other temperatures to determine their behavior under these conditions.

After a system has been developed to prove that sterility has been achieved, the system can be used in conjunction with all sampling and sterility testing to prove and maintain sterile conditions during sampling, assay, and culture. A biological

indicator, while only a small portion, is without a doubt the most important part of the system.

Fig. 1. Spore powder tablets

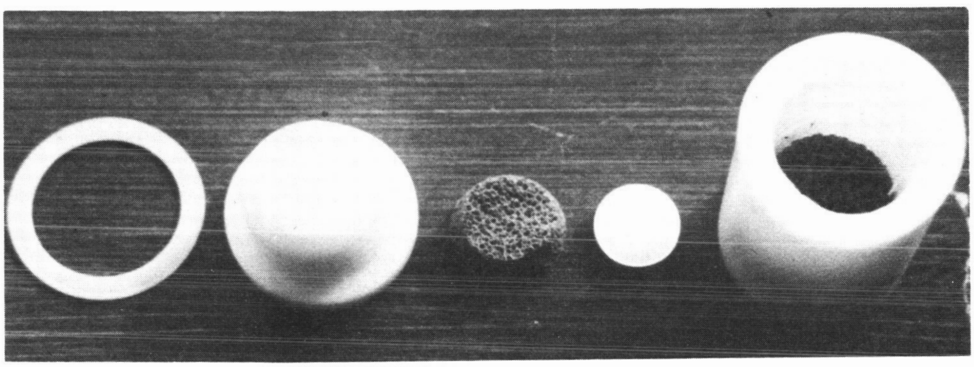

Fig. 2. Disassembled Teflon carrier

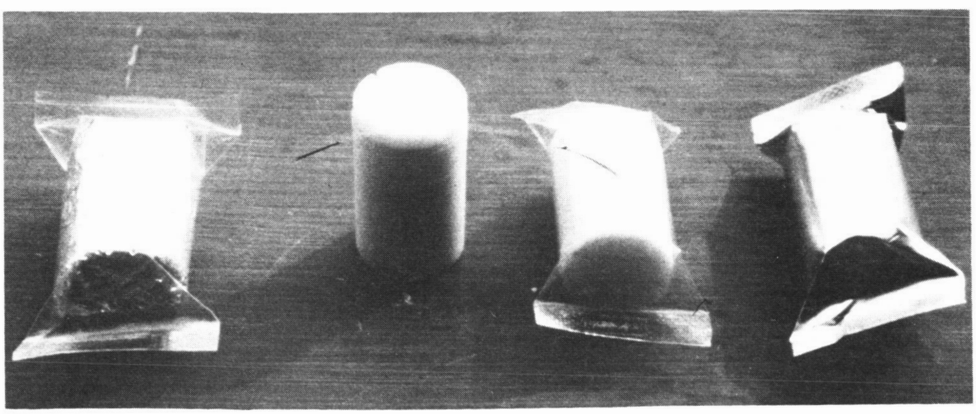

Fig. 3. Carriers encased in Aclar film

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MICROBIOLOGICAL PROFILE OF CLEAN ROOMS
NASA Work Unit 189-58-00-10-55 (FY 1964)
JPL 386-55810-2-3156
J. J. McDade

A study was performed to determine the microbial levels present in a Class II, Class III, and Class IV industrial clean room. Monitoring was performed for a total of 30 days in each of the rooms, and the microbial levels in the air, accumulating on surfaces, and as result of human handling were determined. It was found that the control of a Class II Clean Room environment was of little benefit, that similar microbial levels were found in uncontrolled environments. The microbial levels in the Class III and Class IV Clean Rooms were about equivalent, and both had a level at least a tenth of that in the Class II Clean Room. The number and activity of the Clean Room personnel were generally related to the microbial levels noted. However, there was no experimental delineation of this relationship. Confirmation was made that microbial accumulation on surfaces reaches an apparent maximum in time. No difference in levels was noted between stainless steel, lucite, and glass surfaces. Although certain unresolved problems became evident as a result of this study, sufficient data have been collected so that a valid estimate of the levels of microbial contamination present in industrial clean rooms can be made. As such, this study represents the most extensive and complete program conducted in clean rooms by all NASA contractors to date.

The study consisted of three phases: a Preliminary Phase (Phase I), a Testing Phase (Phase II), and an Evaluation Phase (Phase III). Phase I consisted of defining and establishing the parameters of sampling time, the optimum media for the growth of the microorganisms, incubation procedures, the sampling areas, etc., to be used in the subsequent Phase II. Phase II consisted of monitoring three different classes (Class II, Class III, and Class IV) of clean room environments for a period of 30 days each. The 30-day periods were divided into six periods of five days each. Each Clean Room was monitored for one work week (5 days) six times during Phase II. Phase III consisted of evaluating and reporting the results as they became available.

Copies of the contractor's final report have been forwarded to NASA Headquarters.

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STERILE ASSEMBLY TECHNIQUES
NASA Work Unit 189-58-21-01-55

J. J. McDade

OBJECTIVE

The objective of this work unit is to investigate and develop techniques and procedures which will reliably prevent contamination of sterile parts and materials during assembly of spacecraft subsystems or systems.

ACTIVITIES

A procurement package is being prepared. Emphasis will still be placed on equipment development, actual use situations and reliability of the barrier system to produce and maintain a sterile environment and product. All work is to be conducted in a sterile environment established through use of a microbiological barrier system. Both sterile assembly and sterile repair situations will be evaluated. Emphasis will be concentrated on the microbiological aspects of getting tools and equipment into the sterile work area and removal of the sterile product in some type of protective envelope. The integrity of the barrier will be challenged both chemically (with Freon and/or Helium gas) and microbiologically (with bacterial spores). All phases of the operation will be monitored microbiologically.

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REVIEW OF HEAT AND ETO SPECIFICATIONS

NASA Work Unit 189-58-21-02-55
JPL 386-82301-2-2945
J. J. Iandolo
A. S. Irons

HEAT SPECIFICATIONS - J. J. Iandolo

A limited research study is currently in progress to determine the relative dry heat resistances of several environmentally isolated spore-forming organisms. These organisms were isolated from various assembly areas and facilities ranging from little or no control to rigid environmental constraints. Three distinct colony types have been chosen. The organisms are classified in the genus Bacillus, but, as yet, no attempt has been made at speciation.

Determinations of the heat resistance will be made at three temperatures with clean refractile spores supported on stainless steel. The secondary objective of this phase of the program will be to compare the thermal death time characteristics in still air with those of moving air at 2 different velocities.

The second phase will consist of determining the heat resistance of these organisms and other selected microorganisms embedded in a soluble plastic material, such as methacrylate. The liquid monomer containing the organisms will be polymerized and cut into 1-cm cubes. After heating, the plastic will be dissolved in Acetone and the organisms plated out to determine viability.

Other areas of cognizance in this task include a continuing review of scientific literature to keep abreast of pertinent information. Continuous study is also devoted to the integration of lethality that occurs due to slowly changing lethal come up temperatures.

ETHYLENE OXIDE SPECIFICATIONS — A. S. Irons

Introduction

Examination and review of the existing ethylene oxide (ETO) specifications has become necessary because of the engineering requirement calling for exposure to more stringent environments for all space hardware required to meet type approval and flight acceptance specifications. This calls for an increase in time, temperature, relative humidity, and ethylene oxide concentration over and the rate of application above that stipulated in the Ethylene Oxide Compatibility Specification GMO-50198-ETS-A which has been the JPL working document up until the present time. In addition the requirements imposed by the Sterile Assembly Development Laboratory (SADL) facility have called for further revisions in the original specification.

Objectives

The objectives are as follows:

1. To develop an ETO cycle which will insure compatibility with the specification to be issued for TA and FA testing of capsule system elements.

2. To develop an ETO cycle which will be compatible with the sterilization and decontamination chambers located within the proposed facilities.

3. To develop a more efficient ETO cycle. One which will more consistently sterilize.

4. To determine the sterilizing efficiency of the proposed ETO cycle compared to a standard cycle.

5. To investigate the possible use of carrier gases for ETO, other than Freon 12 (dichlorodifluoromethane).

Accomplishments to Date

1. Two (2) ETO specifications (GMO-50517-ETS and GMO-50518-ETS), have been written that meet objectives one, two, and three of the preceeding paragraph.

2. It has been established that carrier gases other than Freon 12 cannot be used because of the constraints imposed either by the safety requirements or the cost of the heavier chambers required to contain the higher pressures attendant with other gases.

3. A new method of application of ETO humidity and temperature has been developed which will be used in conjunction with the SADL ETO chamber. It was necessary to develop the new method of application because of the chamber size which will be 18 x 18 x 18 ft and have a capacity of approximately 6,000 ft^3.

4. Several methods of removing air and replacing it with the ethylene oxide, Freon mixture were considered

(a) High vacuum - 1-50 torr (1 torr = 1 mm Hg absolute pressure).

(b) Low vacuum - 50-100 torr.

(c) Pulsing - positive pressure and drop to ambient: repeat until proper ETO concentration is reached.

(d) Displacement of air by the 88-12 ETO-Freon mixture.

It was decided that a vacuum cycle would be used and vacuum in the range of 70 ±5 torr would be utilized because of the cost reduction possible and the probable increase in sterilizing efficiency.

Future Activities Planned

If funds are available, it is planned that the proposed cycle will be evaluated and will be compared with the standard cycles used in conjunction with existing equipment. It will be compared on the basis of sterilizing efficiency and the reproducibility of results.

Control surfaces and actual space hardware will be inoculated to check the efficacy of the cycle.

JPL Technical Memorandum No. 33-272, Vol. I

PRESTERILIZATION CLEANING OF SPACECRAFT PARTS

NASA Work Unit 189-58-21-03-55
JPL 386-82401-2-2945

A. S. Irons

OBJECTIVE

The purpose of this study is to establish standard methods of cleaning spacecraft parts, subsystems, and systems, and to determine the effectiveness of these methods in reducing their microbial load.

The study will consider two main aspects of cleaning:

1. Physical removal of soil, grease, or other foreign substances including microorganisms.

2. Destruction of microorganisms. Also to be considered are the properties of any cleaning or decontaminating agent or agents considered for use. The ideal agent should be:

   a. Nonflammable.

   b. Nontoxic.

   c. Stable to heat and moisture.

   d. Easily removed from systems being cleaned and must leave no residue.

   e. Unaffected by materials of construction and shoud have no affect on materials of construction.

   f. Useable at room temperature and have high germicidal and/or sporicidal power.

   g. Low surface tension.

This study is designed to:

1. Survey presently available sporicides, germicides, disinfectants, antiseptics, sanitizing agents, fungicides, chemicals, detergents, and cleaning compounds as well as microbiocidal lubricants and greases and will attempt to determine by experimentation the microbiocidal effectiveness of these compounds.

2. Establish and recommend standard methods of use of the surveyed compounds.

3. Permit the generation of a list of approved chemical compounds which can be used to clean and decontaminate spacecraft parts, tools, and assembly areas. Candidates for this list are such

compounds as peracetic acid for decontamination and the fluorocarbons for cleaning. Combinations will also be considered.

4. Also, consideration will be given to such physical adjuncts as ultrasonics alone and in conjunction with various chemical compounds.

INTRODUCTION

When heat is used as the medium to sterilize any given material, the number of microorganisms associated with the material influences the time and temperature required to sterilize it. As the number of microorganisms is reduced, the time and/or temperature required to sterilize is also reduced. And as the time and/or temperature required to sterilize is reduced, the deleterious effects of the procedure are generally reduced, thereby increasing the reliability of parts subjected to the procedure. With this in mind one can see the obvious advantages of reducing the number of microorganisms associated with space hardware.

When chemical agents are used as the medium to decontaminate or attempt to sterilize any given material, the number of microorganisms associated with the material influences the time of exposure to the chemical agent and the concentration or strength of the agent.

The microbial load affects all other methods of sterilization or decontamination as well. The effort required to sterilize is increased as the microbial load is increased; therefore it is of prime importance that we investigate methods of physically and/or chemically removing microorganisms from any space hardware which will be subjected to a decontamination or sterilization procedure.

ACTIVITIES DURING REPORT PERIOD

A survey was started to develop a tentative list of potential cleaning and disinfecting agents to be included in the work statement which is being prepared for this study. A survey was also initiated to determine the extent of present efforts by industry or aerospace which require the same or similar methods and compounds. A survey was initiated to develop a list which will indicate cleaning - decontaminating agents and material compatibility.

FUTURE ACTIVITIES PLANNED

1. Completion of the work statement and initiation of the investigation of cleaning and disinfecting agents.

2. Preparation of a protocol of standard methods to be used in the cleaning and disinfection of space hardware.

MICROBIOLOGICAL RECOVERY TECHNIQUES/SURFACES
NASA Work Unit 189-58-22-01-55
JPL 386-81401-1-2945
J. Iandolo

OBJECTIVE

The objective of this work unit is to develop techniques for the recovery of sublethally damaged microorganisms.

ACTIVITIES

After a September review of the objectives of this task in Huntsville, Alabama, it was decided to reorient the work statement. The various manufacturing and testing techniques which influence the internal contamination are to be surveyed. Present information tends to support the contention that these processes are so severe as to be autosterilizing. To substantiate this position these techniques are to be documented. Such information as temperature of coating material at time of application, hermetic seals, sealing with inert gas under positive pressure, and postmanufacture reliability tests that involve heat are to be reported.

Since the exterior surfaces are still open to microbial contamination a statement of work has been prepared to assay selected piece part exteriors. This proposal will cover a wide variety of parts and provide basic inputs for the mathematical interpretation of contamination control presently being developed.

After the manufacturing techniques are studied, a more precise definition of needs can be stated as regards the microbial contamination of interiors. If necessary a modification to the proposed contract will be made to encompass this area of research.

MICROBIOLOGICAL EXAMINATION OF SPACECRAFT PARTS/INTERIORS

NASA Work Unit 189-58-22-02-55
JPL 386-81901-2-2945

J. J. Iandolo

OBJECTIVE

The objective of this work unit is to determine quantitatively the amount of microbiological contamination in the interior of spacecraft parts required to be sterile.

ACTIVITIES

In August 1965 work on Modification 3 of the original contract was initiated. The aims of the present task provide for:

1. Detailed study of pulverization techniques to determine the optimum method and particle size.
2. Determination of the conditions for leaching toxic substance and neutralizing the insoluble inhibitors.
3. Development of a growth medium to optimize the recovery of injured organisms.
4. A protocol for the recovery of microorganisms in solid materials.

As of this date, work has progressed on points 1, 2, and 4. The basic experimental plan calls for optimization of the pulverizing and neutralizing scheme before development of a suitable medium. For the most part, model experiments were performed to test several techniques for achieving optimum values for pulverization and neutralization.

Previous results indicated that the most efficient method of pulverization was sawing. Several classes of saws were investigated. A high degree of reliability and consistency was obtained with the hacksaw type. This blade contains 32 teeth per inch in the raker configuration. This type of saw has straight teeth inserted between pairs of left and right set teeth.

Concurrently, neutralization and leaching were investigated. These data have shown that effective measures can be taken against the epichlordydrin inhibitors. This class of compound is distinctive in that it occurs frequently in epoxy-type polymers. Both the free unreacted epichlorhydrin and the terminal variety of the polymer molecule are inhibitory. However, the toxic action can be substantially reduced by reaction with imidazo nitrogen as contained in histone like proteins or nucleotides.

Further investigative efforts are being pursued to identify and counteract other potent molecules which may occur in differing spacecraft materials.

With the information currently available, a provisional protocol has been prescribed which embodies the above considerations. However, this protocol is

recognized to be somewhat deficient and is intended to represent the state of the art at this time. As new developments occur they will be written into the protocol.

The selection of a proper medium has been dependent upon optimization of the pulverization and neutralization techniques. When a satisfactory degree of efficiency is obtained this phase will be initiated.

At the present time, actual recovery experiments are in process to determine the status of the pulverizing and neutralizing methods.

AUTOMATED MONITORING OF MICROBIAL CONTAMINATION

NASA Work Unit 189-58-23-01-55
JPL 386-82501-2-2945

J. J. McDade

OBJECTIVE

The objective of this work unit is the development of methods of automatic sampling, recovery, and assaying of microbiological flora.

ACTIVITIES

Visits have been made to two installations involved in the development of automated systems for the rapid detection of microorganisms. The two laboratories visited were the Douglas Aircraft Company and the University of California, Virus Laboratory at Berkeley, California. The Douglas approach has been aimed at the rapid detection of pathogenic microorganisms disseminated as bacteriological warfare agents. As such, this system has possibilities of being modified for use in the space hardware sterilization program. Similarily, Dr. Glasser's system may also be of value as a procedural supplement to the microbiological monitoring scheme that will be used to provide some documentation required for certification of the sterility of flight capsule hardware.

A visit to the U. S. Army Biological Laboratory at Fort Detrick is scheduled for early 1966. Following this, all of the systems will be reviewed and modified for application in the sterilization program. Then, a work statement for RFP will be prepared. If possible an effort will be made to modify a developed system. Emphasis will be placed on the development of a system for the recovery of microorganisms from ultraclean environments such as laminar flow clean rooms.

The possibility exists of combining present automated monitoring of inanimate particulate matter with newly developed methods of microbial detection to form a system that will give an immediate response to changing environmental conditions in a spacecraft assembly area.

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Part D
Manned Space Sciences

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MANNED SPACE SCIENCES (190)

PLANETOLOGY (190-42)

SPECTRAL PHOTOGRAPHY
NASA Work Unit 190-42-03-01-55*
JPL 390-10101-2-3250
John B. Adams

OBJECTIVE

The objectives of this work unit are to develop (1) a photographic system capable of sensing faint differences in spectral reflectivity on a planetary surface and showing these differences on a high-resolution image, (2) a basis of geologic (and biologic) interpretation of these data, and (3) a spectral photography experiment for use aboard manned, orbiting spacecraft.

PROGRESS

The principal progress on the photographic part of this investigation has been theoretical rather than experimental. This is primarily the result of the necessity to develop the application of advanced analytical techniques to this specific problem in order to provide parameter tradeoff decision criteria and to provide a method of quantitative error analysis of the experimental implementation. A contributing factor has been the temporary inadequacy of both observatory and laboratory facilities.

Lunar spectral photographs have been obtained during four full Moon periods under a current Lockheed contract. The processing of these photographs has been extremely time consuming, and uncertainty has arisen because of visible spurious effects, which are suspected as being the result of erratic camera operation. In addition, a more serious problem has emerged in that the Stony Ridge Observatory has no capability of measuring the spectral transmittance of the telescope system or the atmospheric optical path. This information is essential in reducing the spectrophotometric data. Furthermore, because of the geographic location of this observatory, the atmosphere is so variable that the use of averaged or approximate data is unjustifiable. Therefore, because of manpower and cost considerations, it was decided to base the experimental implementation of this investigation on exposures using the 24-in. telescope being constructed at Table Mountain Observatory. This arrangement will provide ready instrument access and will justify the necessary investment in both time and money for site and instrument calibration.

During the analysis of the data acquisition and processing procedures being used in this investigation, it became apparent that the straightforward analytical technique had certain shortcomings. This approach does not provide adequate optimization criteria nor does it provide a suitable basis for quantitatively evaluating experimental accuracy. Therefore, it was undertaken to apply the analytical techniques of generalized Fourier analysis and information theory to this problem. The relatively recent optical and photographic literature shows that these techniques which have been so successful in the analysis of electrical communications systems

*Jointly funded under NASA Code 185-42-20-27-55

are being successfully applied to the transfer and processing of optical imagery data. The application of these techniques to this problem is currently proceeding with satisfaction. The principal result of this analysis will be that the experimental implementation of the photographic part of this investigation will proceed on a more valid and justifiable basis.

Work continues on the study of the spectral reflectance of minerals, glasses, and rocks in the laboratory. The initial investigation has centered on the effects of geometrical changes of the sample on the spectral response. The first runs, using samples having a variety of compositions and optical properties, showed a general reddening of rock powders in comparison with their corresponding solids (Fig. 1). A general theory involving internal reflection in the particles and wavelength dispersion of the refractive indices has been used to explain the reddening of the powders. The applicability of the theory has been verified by experiments in which internal reflection was greatly reduced by surrounding the grains with liquid of high refractive index, and, by experiments using glasses and minerals having widely different dispersions. The internal reflection-dispersion theory predicted that other shifts in spectral reflectance should occur with changes in particle shape and packing and with ultragranulation such that the grain sizes approach the wavelength of the light.

Preliminary experiments with particle shape and packing indicate that, as predicted, reddening also occurs as the particles approach spheres and as the packing becomes more open. Measurements using very small particles have been hampered by the difficulty and time involved in separating size fractions in the 0-10 μ range. The recent (November, 1965) addition of A. Filice to the project on a part-time basis has greatly facilitated this work, and, several fractions down to the 0-2 μ size have now been run on the spectrophotometer. As the particle diameters approach λ the concepts of internal reflection and dispersion cease to apply in a simple way. Powders made up of 0-2 μ particles reverse the reddening of the "coarser" powders, and, in general, have a rather flat spectral response and a very high integral reflectance when packed.

An additional effect which is of interest for interpretation of lunar data has been noted by Hapke, 1965. He reports that simulated solar irradiation (H^+ bombardment) causes rock particles to redden. We intend to investigate this phenomenon in the laboratory in cooperation with D. Nash who has been studying radiation damage, darkening, and proton-induced luminescence of silicate rocks.

The reflectance changes due to changes in sample geometry that we have observed in the laboratory are of the same order as the spectral differences observed on the Moon. Although it is premature to explain the lunar spectral differences at this time, it is significant that factors other than compositional differences can enter into the geologic interpretation of the lunar spectral data.

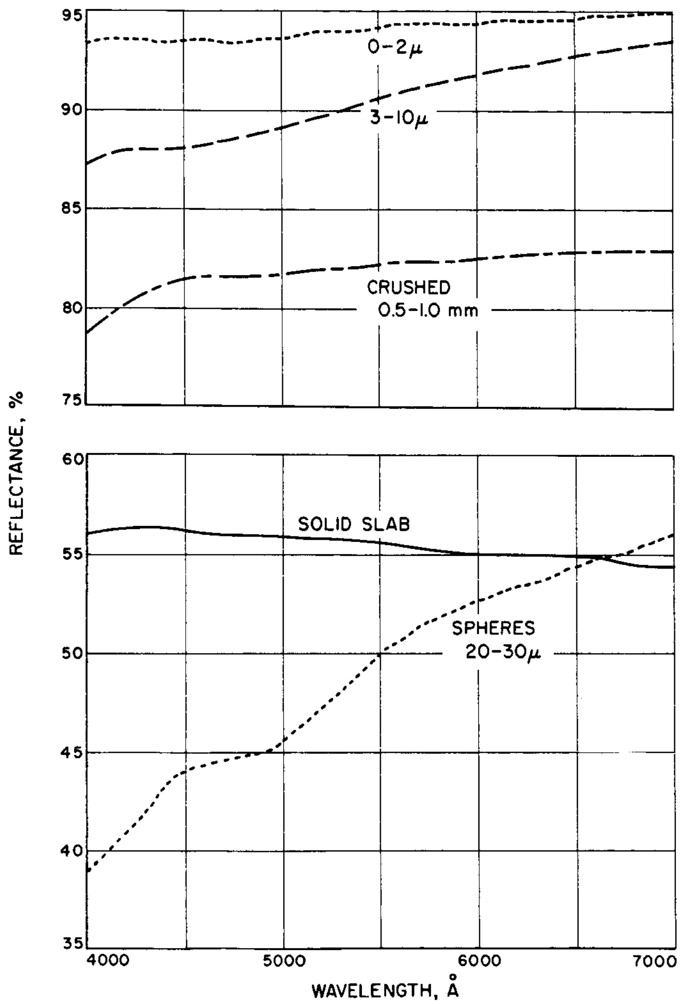

Fig. 1. Reflectance curves for clear quartz showing slope changes for different size fractions and grain shapes

LUNAR AND PLANETARY X-RAY DIFFRACTION PROGRAM
NASA Work Unit 190-42-03-02-55*
JPL 390-20401-2-3250

R. C. Speed
A. C. Dunk

OBJECTIVE

The objectives of the lunar and planetary x-ray diffraction program are to prepare flight diffraction systems for both manned and unmanned lunar and Martian vehicles and to perform associated research on handling and processing of diffraction data and quantitative interpretation of multiphase diffraction data.

Shortly after the beginning of FY 1966 the NASA job number for this task was changed from OSSA 867-14-00-01-55 (NASA/JPL Task Order Number RD43) to the current number and therefore a report for the above number only is provided. Instrument procurement is severely limited by lack of funds.

PROGRESS

Work in this program in FY 1966 has consisted of further evaluation of possible diffractometer components and techniques with views toward delineating optimum systems for each flight goal as well as determining the nature of the best general system. Theoretical and experimental analysis has indicated that the electron gun source and Bragg-Brentano geometry is the best general combination. Virtually all components to this system have been breadboarded and tested; the construction of a prototype which integrates all concepts and designs is the next step and so far has been hindered by lack of sufficient funds.

Specific progress in five areas of this program are discussed below.

AES FIELD TEST

A major goal in the diffraction program is to evaluate the diffraction technique in conjunction with scientists at the United States Geological Survey (USGS) and Goddard Space Flight Center (GSFC) as an exploration tool for scientist-astronauts in the AES program. The first test was conducted at Hopi Buttes, Arizona, with the USGS, and JPL supplied a prototype diffractometer for this effort. The system performed well for the duration of the test except for the malfunction of a commercial laboratory power supply which was immediately replaced. Some 70 diffraction patterns of specimens collected by USGS geologists were taken, and near-real time interpretation of the data was made by JPL geologists. The preliminary result of the test indicated that partial real time analysis of the major phases of the diffraction pattern can be made and that this system could be useful in assisting astronauts at determining the most critical problems to be investigated during an exploration period. As a consequence, a real time computer analysis and visual presentation scheme for astronaut use has been conceived and written up.

*Jointly funded under NASA Code 185-37-20-02-55

PREPARATION FOR FUTURE AES TESTS

Preparations have been conducted at JPL for future AES field tests of the x-ray diffractometer. An integrated circuit detector preamplifier has been fabricated, tested and installed in the field test diffractometer (modified model P-4). The diffractometer has been modified further to make command input circuitry more compact and convenient to use. The model P-4 compartment B has been repaired and mechanically integrated with the P-4 goniometer. Analytical instrumentation to handle detector output has been evaluated, and recommendations made to the USGS, based on compactness, function, and interface suitability. Once this instrumentation has been obtained, final integration will be accomplished at JPL, then the entire system transferred to the USGS for further field testing.

ANCILLARY X-RAY FLUORESCENCE INSTRUMENTATION

During the period of this report, work has continued in the area of ancillary x-ray fluorescence instrumentation. The ultimate goal of this work is the utilization of presently unused portions of the diffractometer x-ray tube output to provide limited chemical information on diffractometer specimens.

Balanced filters of Mg, Al and Si were prepared for Al and Si analyses (Ref. 1). The sensitivity achievable for Al analysis in a matrix rich in Si was found to be about five times better than for Si in an Al rich matrix. The sensitivity in the latter case (2 wt % Si in an Al matrix), however, is comparable to that achievable using mathematical or electronic manipulation of raw pulse amplitude data (standard non-dispersive analysis).

A balanced filter pair has also been made for Fe analysis. A set of standards of iron in Z - 1, Z - 2, and Z + 2 matrices has been prepared to investigate sensitivities achievable in the $Z \simeq 25$ region.

The work described above has been conducted using standard laboratory x-ray spectrographic equipment. This approach will be continued until preliminary (optimum) data have also been obtained for the elements Ni, Ca, and K, at which time a breadboard apparatus will be constructed to simulate the geometry of the lunar x-ray diffractometer in order to establish sensitivity limits achievable under the nonoptimum conditions of the objective application.

EVALUATION OF A SINGLE CRYSTAL MONOCHROMATOR AS APPLIED TO A MINIATURIZED X-RAY DIFFRACTOMETER

In order to suppress unwanted fluorescence and scattered continuum radiation generated in diffraction specimens, pulse height analysis is employed in the Mark I (Surveyor) diffractometer. Curved crystal monochromatization of the diffracted beam offer an alternative method of accomplishing this task more efficiently, but with a loss in peak intensity. In order to evaluate the relative merits of crystal and electronic dispersion techniques, a single-crystal monochromator utilizing a curved LiF crystal was designed, fabricated, and attached to the breadboard model diffractometer.

Peak parameters of the quartz (101) and the forsterite (130) reflections were obtained with and without the monochromator. These data are tabulated in Table 1.

Optimum PHA settings were employed in the collection of the Fo data without the monochromator.

Table 1

Without Monochromator	Qtz (101)	Fo (130)
P-B	3086	257
P-B/B	32.5	5.5
W/2	0.20	0.20
With Monochromator		
P-B	1869	181
P-B/B	62.3	12.9
W/2	0.24	0.25

Further studies are planned using the monochromator. These include peak-to-background versus intensity and resolution for common rock specimens, detector high voltage power supply stability parameters, and x-ray tube alignment requirements.

SCANNING-MODE OPTIONS

Some thought and preliminary experimental work have been directed toward the problem of lunar diffractometer scanning mode, i.e., rate and type of scan as a function of power-time product. This work is summarized in Ref. 2. At this writing, it appears that straightforward power time versus precision and angular resolution tradeoffs can be effected using digital scanning with shaft position encoding. Breadboard instrumentation has been built which will allow precise and rapid evaluation of performance-power tradeoffs. In addition, a breadboard optical shaft angle encoder is being designed and fabricated. It is anticipated that a flight diffractometer will be capable of providing acceptable diffraction data on lunar samples operated at approximately one tenth the power-time product of the Mark I (Surveyor) diffractometer.

DIFFRACTOMETER DEVELOPMENT (JPL 390-20402-2-3220) -- A. C. Dunk

The long range objective of the task is the development of an x-ray diffractometer instrument which can be used on lunar and planetary missions to make crystallographic analysis of the local soils.

Part of the current effort involves redesigning the electronic circuits where possible to improve reliability and reduce weight and power consumption. The proportional preamplifier has been redesigned using integrated circuits, and has been successfully tested. The high voltage (25 kv) power supply has been reworked and continuous operation successfully accomplished. This prototype power supply is

currently submerged in transformer oil and enclosed in a metal can, which is designed to be hermetically sealed. This is a satisfactory package functionally, but effort will be directed toward reducing the weight and size of the power supply to meet anticipated spacecraft weight constraints.

Technical support for the experimental studies being performed by N. Nickle and J. Dunne was also provided during this period.

The effort for the second half of FY 1966 will include the development of a breadboard shaft-angle encoder which will provide an unambiguous digital readout of the diffraction angle.

A study of the effects of step scanning, scanning speed, and scanning modes on resolution will be made to determine what improvements in power-time profile are possible.

A study of a new type (LND) of side window (Beryllium) proportional counter is also planned. This counter tube has just been received.

FUTURE WORK

In summary, future work should consist of

1. Further field testing of the diffraction technique as a tool for lunar astronauts.
2. Fabrication of a general diffraction system prototype which incorporates the most valuable diffraction concepts in a single box, which can be subjected to complete laboratory scientific and engineering tests, and which ultimately can be used in field tests of AES instruments.

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AIRBORNE MICROWAVE RADIOMETRY

NASA Work Unit 190-42-20-16-55
JPL Job No. 390-20301-02-3250

F. T. Barath

OBJECTIVE

This work unit is part of the Passive Microwave Program directed by the Manned Space Science Office within the framework of their Remote Sensing Program. The objectives are: (1) to provide passive microwave instrumentation for aircraft use and to perform extensive measurements with it; and (2) to coordinate the Passive Microwave Team activities.

PROGRESS

In the first area, two dual-channel radiometers operating at 13.5 and 19 mm, and 8.5 and 33 mm wavelengths have been installed aboard the NASA-MSC Convair 240A aircraft as shown in Fig. 1. The installation permits variable incidence angle and variable polarization measurements. Such measurements have been performed over the Galveston Bay, the Mono Lake area, the Cascade Glacier area, and over agricultural, urban, and forestry areas. Analysis of the data and correlation with data from other sensors (IR, radar, optical) is presently under way in conjunction with MIT. These measurements and the data analysis will continue through next year.

An agreement has been negotiated with North American Aviation for the loan of an advanced passive imager. This instrument will provide stereoscopic images of the terrain below the aircraft. Delivery and installation aboard the NASA P3V aircraft will occur during the next 3 months, and an extensive measurement and data analysis program will continue through next year.

A contract has also been placed with Raytheon to provide ground-based backup measurements. These are performed from a mobile radiometric station. Measurements have been made in the Mono Lake area, but technical difficulties have delayed further work until January. It is anticipated that the measurement program will continue for a minimum of 6 months. The data analysis for these measurements will be done at Raytheon, JPL, and MIT.

In the second area, considerable effort has been expended and will be expended in coordinating the various laboratory, field, and flight activities of a large number of organizations involved in passive microwave work. These include OSU, MIT, JPL, Raytheon, GSFC, Navy, Scripps, North American Aviation, and others.

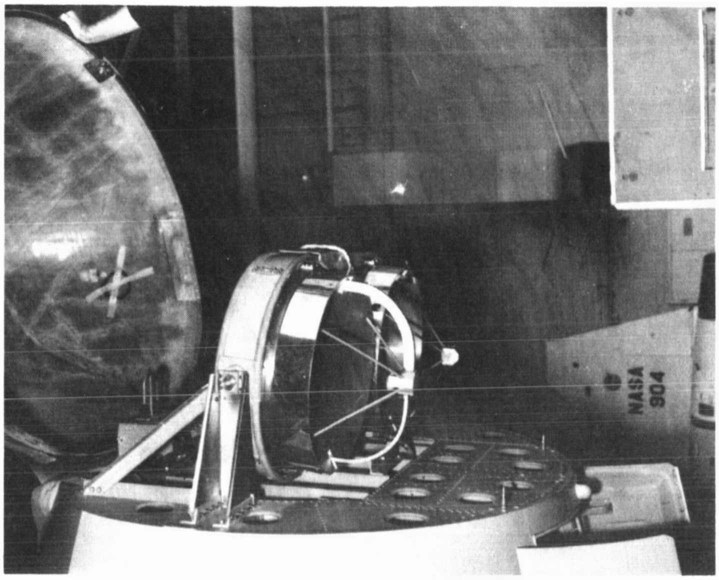

Fig. 1. Dual-channel radiometers

INFRARED THERMAL EMISSION FROM SILICATES

NASA Work Unit 190-42-20-20-55*

JPL 390-20101-2-3250

J. E. Conel

OBJECTIVE

This work unit has as its objective the development of an infrared spectroscopic experiment to carry out spectro-photometric observations of planetary surfaces in the spectral region 8-14μ for obtaining remote petrologic information. The specific objectives for this fiscal year include laboratory and theoretical studies of silicate emission spectra, development of a portable field instrument, and ground-based field studies at NASA-designated test sites.

INTRODUCTION

Spectral analysis of emitted planetary thermal radiation between 8-40μ is under study for use in remote compositional mapping of planetary surfaces. Our current program consists of theoretical and laboratory studies, and development of instrumentation for extension of this method to the field. Work in each of these areas is summarized.

LABORATORY AND THEORETICAL STUDIES

Previous reports have described in detail results of past laboratory investigations carried out between 8-14μ. The general conclusion reached from experimental work was that roughening and/or granulation produces dramatic changes in the emission spectra of silicates. Thermal emission from granulated material becomes spectrally featureless as geometric complexity of the emitting surface increases. With sufficient instrumental sensitivity ($S/N \geq 100$) compositional information can still be obtained even with "fairycastle" structured surfaces if the materials are mineralogically simple. In certain assemblages, especially those containing quartz, displacements of emission minima to shorter wavelengths accompanied granulation as well.

A search for the physical reasons behind such changes in emission spectra continues. Reflection spectra between 8-40μ of 25 igneous and metamorphic rocks of widely varying mineralogical composition and texture were made as a prelude to emission analysis of the same materials both in solid and granulated form. The survey was extended to 40μ to investigate the possibility of other peak shifts occurring in the region 15-40μ. An effort was made to achieve absolute accuracy of 1%. Several months of frustrated effort culminated in the discovery that the programmed slits of the Beckman IR-7 are not reproducible from scan to scan. Also, using a newly acquired Huggins Mark IX radiometer, we learned that both specimens and blackbodies used in previous work, contain substantial thermal nonhomogeneities (total radiation brightness temperature differences of up to 30°C over one square inch). These difficulties actually precluded the possibility of accurate absolute work from the outset.

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Preliminary emission studies with the new suite of rocks also disclosed substantial departures from black behavior of the blackbody (lamp black cup) then in use. A one-square-inch blackbody was constructed of Schick single-edge stainless steel razor blades packed side to side. The sawtooth surface so obtained is directionally very black and increases in blackness with darkening due to surface oxidation of the blade edges. We rejected this device as a radiation reference with our grating spectrometer because it emits strongly polarized light, as is easily seen by changing the direction of grooving relative to the spectrometer slits. In all probability a similar difficulty will accompany use of any such grooved radiator with an instrument whose response depends upon polarization of the incident beam.

An improved conical blackbody cavity (half angle 24°) and furnace are now under construction and will be completed in mid-January for use in these refined emission studies.

Discovery of the highly nonisothermal state of all specimens (especially granulated material) used in previous emission work has led to a theoretical study of the spectral consequences of such nonuniformity, which will be the situation with most natural targets. We illustrate the difficulties involved with a simple example. Suppose that a solid is characterized by a variation in emissivity describable by the Lorentz-like formula

$$\epsilon_\lambda = 1 - \frac{\rho_{\lambda m}}{\left[(\lambda - \lambda_m)/\delta\right]^2 + 1} \tag{1}$$

where ϵ_λ is the spectral normal emissivity at wavelength λ, $\rho_{\lambda m}$ is the maximum spectral normal reflectivity at wavelength λ_m, and δ is the bandwidth for which $\rho_\lambda = 1/2\,\rho_{\lambda m}$.

To simplify the analysis further, the source area taken to be unity is divided into N equal areal increments each characterized by a constant temperature T_i. The apparent spectral emissivity of such a solid is, by definition,

$$\bar{\epsilon}_\lambda = \frac{\epsilon_\lambda}{N} \frac{\sum_{n=1}^{N} B_\lambda(T_i)}{B_\lambda(T_r)} \tag{2}$$

where $B_\lambda(T)$ is the Planck function and T_r is a reference temperature such that $T_r \geq T_i (1 \leq i \leq N)$ to insure $\bar{\epsilon}_\lambda \leq 1$ for all λ. Empirically it was found that for $N = 3$ and $T_i - T_{i+1} = 10°K$ that $\bar{\epsilon}_\lambda$ is closely approximated by the function*

*Murcray (1965) reports some recent telescopic observations of the spectral dependence of lunar emissivity between 8.3 and 10.4 μ, excepting the spectral region of ozone absorption near 9.5 μ. The emissivity falls off with increasing wavelength and the observations can generally be fitted by a function like $\epsilon_\lambda = \alpha - \beta(\lambda - \lambda')$. This is suggestive of the possibility that source (i.e., lunar surface) temperature variation over the field of view is producing the effects observed. The data is of doubtful value for interpretation in terms of source composition or for radiation calculations. Observations to 12 μ and beyond would clarify whether compositional or temperature effects are producing the trends observed.

$$\bar{\epsilon}_\lambda = \epsilon_\lambda \left[\alpha - \beta(\lambda - \lambda') \right] \tag{3}$$

where α and β are constants and λ' is some constant reference wavelength. Using the formula (1) for ϵ_λ and expanding $\bar{\epsilon}_\lambda$ in Taylor series about λ_m,

$$\begin{aligned} \bar{\epsilon}_\lambda = {} & (1 - \rho_{\lambda m}) \left[\alpha - \beta(\lambda_m - \lambda') \right] - \beta(1 - \rho_{\lambda m})(\lambda - \lambda_m) \\ & + \frac{[\alpha - \beta(\lambda - \lambda')]}{2!} \frac{2}{\delta^2} \rho_{\lambda m} (\lambda - \lambda_m)^2 - \frac{6\beta \rho_{\lambda m}}{3!\,\delta^2} (\lambda - \lambda_m)^3 + \ldots \end{aligned} \tag{4}$$

to third order. Differentiating this with respect to λ and setting the result equal to zero gives a quadratic equation whose two roots are

$$\lambda - \lambda_m = \frac{1}{3}\left[\frac{\alpha}{\beta} - (\lambda_m - \lambda')\right] \pm \sqrt{\frac{1}{9}\left[\frac{\alpha}{\beta} - (\lambda_m - \lambda')\right]^2 + \frac{1}{3}\delta^2 \left(\frac{1}{\rho_{\lambda m}} - 1\right)} \tag{5}$$

The (+) and (-) signs are associated with the subsidiary maximum and minimum introduced in Planck's function by the assumption of a Lorentz line shape for ϵ_λ. The ratio α/β becomes infinite as temperature uniformity is approached or the reference temperature approaches the average brightness temperature of the source. As $\beta \rightarrow 0$,

$$\frac{1}{3}\left[\frac{\alpha}{\beta} - (\lambda_m - \lambda')\right]^2 \gg \delta^2 \left(\frac{1}{\rho_{\lambda m}} - 1\right)$$

and $\lambda \rightarrow \lambda_m$. Equation (5) also shows that λ_m is apparently displaced to shorter wavelengths as δ, the bandwidth of the emission band, increases or $\rho_{\lambda m}$, the maximum reflectivity, decreases. Choosing values for λ_m, λ', δ typical of silicates has shown that the effect is significant only if $\rho_{\lambda m} < 0.1$.

The above arguments qualitatively explain the peak shifts observed experimentally and reported in previous summaries. They suggest that source temperature nonhomogeneities (apart from fluctuations) can introduce unpredictable spectral aberrations that grow in importance as emission bands increase in width and decrease in depth, changes in emissivity that are always brought about in silicates by granulation.

A fundamental experimental problem associated with data interpretation in both field experiments and actual planetary observations is accurate determination of the equivalent blackbody temperature of the source, assuming such a temperature can actually be defined. For nonisothermal targets the definition of equivalent blackbody temperature is obviously not possible. For cases where such definition is possible a radiometric method is desired which provides a temperature independent of the emissivity. The multicolor brightness temperature method seems most desirable from this standpoint and is under study. In this method it is assumed that the source emissivity in a specified spectral region can be approximated by a polynomial of the form

$$\epsilon(\lambda) = \epsilon_0 + \epsilon_1 \lambda + \epsilon_2 \lambda^2 + \cdots \pm \epsilon_n \lambda^n \qquad (6)$$

where the ϵ_n are constants. Brightness temperature measurements T_{bn} are made at n + 2 wavelengths. Assuming the Wien approximation to Planck's law this gives sufficient data for solution of the n + 2 simultaneous equations

$$\exp\left[\frac{C_2}{\lambda_n}\left(\frac{1}{T} - \frac{1}{T_{bn}}\right)\right] = \epsilon_0 + \epsilon_1 \lambda_n + \epsilon_2 \lambda_n^2 + \cdots \qquad (7)$$

for the unknowns T and ϵ_n. If the sources are spectrally gray in some region, as silicates, both powdered and otherwise, are near 7.5μ, then the polynomial simplifies to a single constant term, and brightness temperature measurements at two wavelengths λ_1, λ_2 allow determination of the unknowns 1/T and ϵ_0. The expression for T in this simple case is

$$T = \frac{(\lambda_1 - \lambda_2)\, T_1\, T_2}{\lambda_2 T_2 + \lambda_1 T_1}. \qquad (8)$$

If $\lambda_1 \simeq \lambda_2$, then $\frac{\delta T}{T} = \frac{\delta T_1}{T_1} + \frac{\delta T_2}{T_2}$

a 1% measurement in brightness temperature at each wavelength thus provides a 2% measurement of absolute temperature, which is independent of ϵ_0. An analogous procedure is used if higher order terms are retained on the right side of Eq. (7).

Recent lunar observations of Shorthill and Saari (1965) which disclosed a highly nonuniform cooling of the eclipsed Moon have prompted an analysis of these results in terms of variations in lunar infrared emissivity. Among other things their observations show that major ray and other craters remain hotter than their surroundings during eclipses and are cooler during full moon. This is precisely the behavior expected theoretically if such craters have better thermal properties (higher values of surface thermal inertia) than the surrounding terrain. This is the simplest explanation of the results, but the effects produced by varying the albedo and infrared emissivity in these areas are not known. Two approaches to this problem were pursued. The first used the theory of heat conduction with a linearized radiation boundary condition. The analysis is only approximate and is very complicated because of the periodic, though discontinuous, nature of the insolation term. The second simpler approach utilizes the homologous transformation, which has been applied to similar lunar problems by Sinton (1962).

The conclusions reached are:

1. Raising the albedo keeping emissivity constant lowers both day and night temperatures, this theoretically demands poorer surface properties.

2. Lowering infrared emissivity keeping visible reflectivity constant raises surface temperatures and theoretically demands better surface thermal properties.

3. From the viewpoint of the boundary conditions, decreasing the infrared emissivity is equivalent to lowering the albedo and is equivalent to increasing the surface thermal conductivity.

4. Explanation of the observed anomalies is afforded by assuming higher visible reflectivity together with a lower infrared emissivity. Such a sympathetic combination of effects is not to be expected based on our laboratory experience.

FIELD STUDIES AND INSTRUMENTATION

In the field observations we will study two important questions: (a) effects of photometrically nonhomogeneous targets on spectral observations, (b) influences of atmospheric radiation, absorption, and scattering in the 8-14μ region. The first question bears on interpretation of data obtained from rough lunar terrain; the second is an attempt to analogize and simplify the problem of interpreting lunar telescopic data.

A spectrometer system of high sensitivity, the details of which have been discussed in previous reports, is under construction at the present time. All major components of the system are now in hand. Fabrication and calibration of the system will be carried out in the next two months. Preliminary field studies will be instigated in March.

The interpretation of terrestrial field data is complicated by atmospheric emission and absorption. For our instrument system, the signal at the detector $\Delta I(\lambda)$ is

$$\Delta I(\lambda) = H(\lambda)\left[B_\lambda(T_r) - \epsilon_\lambda B_\lambda(T_s) e^{-k_\lambda \rho u} - B_\lambda(T_a)\left(1 - e^{-k_\lambda \rho u}\right)\right] \tag{8}$$

where

$H(\lambda)$ = instrument transmission function

T_r = reference temperature

T_s = source temperature

T_a = atmospheric temperature

ϵ_λ = source emissivity

$k_\lambda \rho$ = atmospheric absorption coefficient (cm^{-1})

u = path length in atmosphere.

For simplicity we have assumed an isothermal atmosphere in the derivation.

The quantity of interest in Eq. (8) is ϵ_λ. In an actual experiment involving large, distant targets, it is not possible to compare target radiation with that from a black reference at the source, so that the source emissivity must somehow be extracte from atmospheric effects. This requires determination of T_s, T_a, and $k_\lambda \rho$. If $T_r = T_s = T_a$, (8) reduces to

$$\Delta I(\lambda) = H(\lambda) B_\lambda (T_r)(1 - \epsilon_\lambda) c^{-k_\lambda \rho u} \tag{9}$$

This shows directly that if $k_\lambda \rho$ is sufficiently large, $\Delta I(\lambda) = 0$. The radiation thus observed will be spectrally black and contain no information whatsoever about source spectral emissivity. In practice, without a comparison measurement, the exponential terms in (8) and (9) must be evaluated independently for specified atmospheric conditions. Telescopic observations of the Moon in the 8-14μ region imply that under suitable conditions $k_\lambda \rho$ is not too large even for the total atmospheric column.

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